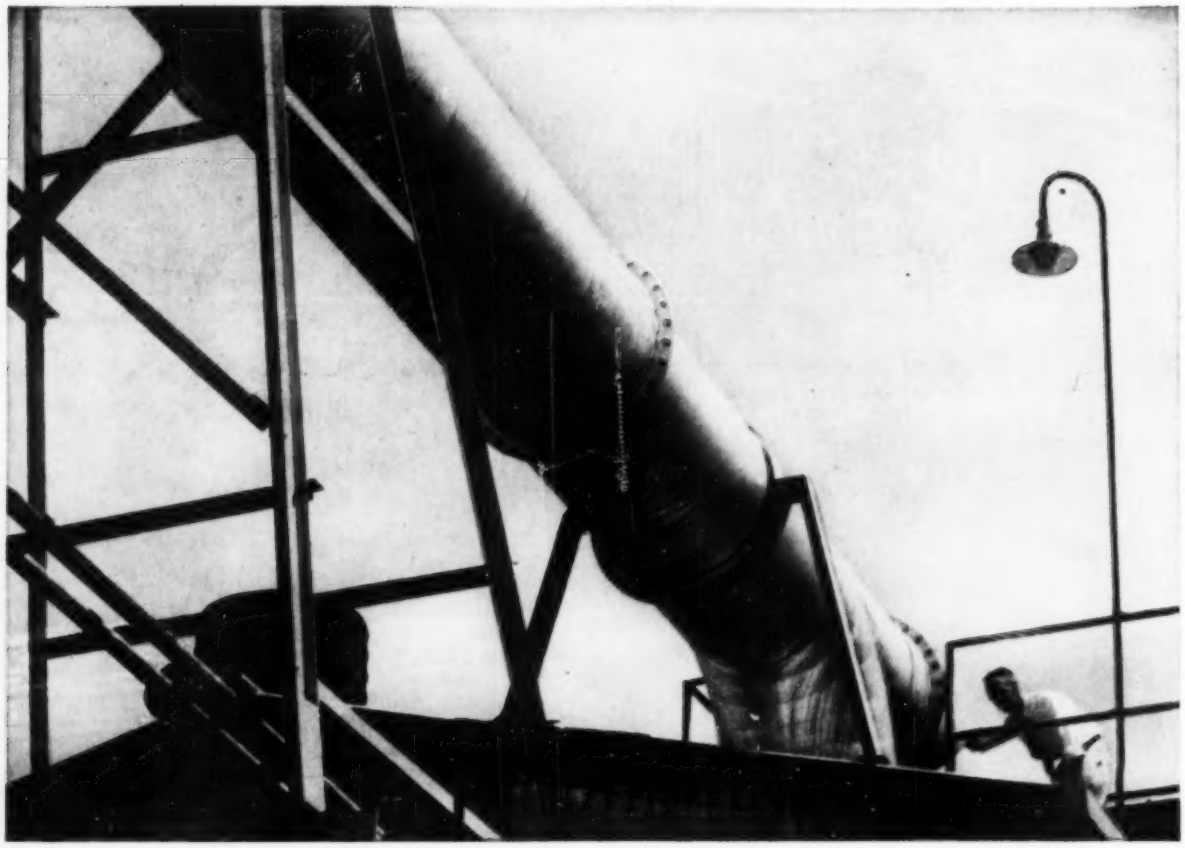
SEPTEMBER 1953

Chemical Engineering Progress

PUBLISHED MONTHLY BY THE AMERICAN INSTITUTE OF CHEMICAL ENGINEERS



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Chemical Engineering Progress

SEPTEMBER, 1953

Volume 49, No. 9

Editor: F. J. Van Antwerpen

OPINION AND COMMENT

453 ENGINEERS LEAVE HOME—WHY?

ENGINEERING SECTION

455 THE FLUIDIZED-BED SULFATE ROASTING OF NONFERROUS METALS
F. M. Stephens, Jr.

459 AGITATION OF VISCOUS SOLID-LIQUID SUSPENSIONS
F. S. Hirsekorn and S. A. Miller

467 THE ROLE OF POROSITY IN FILTRATION
F. M. Tiller

480 FACTORS INFLUENCING PROPERTIES OF SPRAY-DRIED MATERIALS Part II
J. A. Duffie and W. R. Marshall, Jr.

487 REPLACEABLE MICRONIC FILTERS—A NEW TOOL FOR THE CHEMICAL ENGINEER
Edward Kane

491 BENCH SCALE EQUIPMENT FOR REACTIONS AT HIGH PRESSURE
A. M. Whitehouse, P. L. Golden, R. W. Hiteshue and E. L. Clark

497 LIQUID-LIQUID EXTRACTION AT HIGH FLOW RATES IN A SPRAY TOWER
J. F. Fleming and H. F. Johnson

503 SCINTILLATION COUNTERS FOR CONTINUOUS ANALYSIS UNDER HIGH PRESSURE
H. G. Drickamer, K. D. Timmerhaus and L. H. Tung

506 WHY DOES THE CHEMICAL ENGINEER SUCCEED OR FAIL WITH PEOPLE?
R. S. Schultz

508 SULFUR-GAS THERMODYNAMICS
E. R. McCartney

510 PLASTICS CEMENT REFERENCE SHEET
R. B. Seymour and R. H. Steiner

NEWS

19 NATIONAL SURVEY QUESTIONNAIRE Part III
22 INDUSTRIAL NEWS
26 MARGINAL NOTES
33 DATA SERVICE
46 A.I.Ch.E. CANDIDATES
68 FUTURE MEETINGS
71 LOCAL SECTIONS
73 NEWS ABOUT PEOPLE
78 CLASSIFIED
82 THE PRESIDENT SAYS . . . W. T. Nichols

4 • 8 • 10 LETTERS TO THE EDITOR
12 NOTED AND QUOTED

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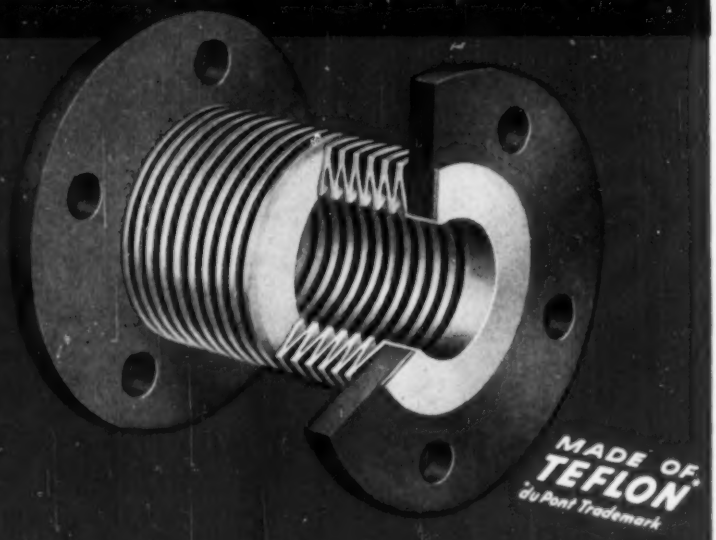

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LETTERS TO THE EDITOR

THE SHERWOOD NUMBER—AYE

Comment on the suggestion in our July issue by B. H. Sage that a new dimensionless group be recognized in honor of T. K. Sherwood was prompt. We sample here a few typical reactions. —Editor

. . . an appropriate manner of honoring Sherwood for his work in material transfer.

CHARLES D. LUKE
Chairman, Dept. of Chemical Engineering
Syracuse University

The proposed designation of the widely used dimensionless group in material transfer as the Sherwood number is an appropriate tribute . . . .

JAMES COULL
Professor and Head
Chemical Engineering Department
University of Pittsburgh

. . . only right and proper to honor Sherwood by this means. The marked advances in chemical engineering theory made by the American investigators have been insufficiently recognized in the world press.

ROBERT BOARTS
Department of Chemical Engineering
University of Tennessee

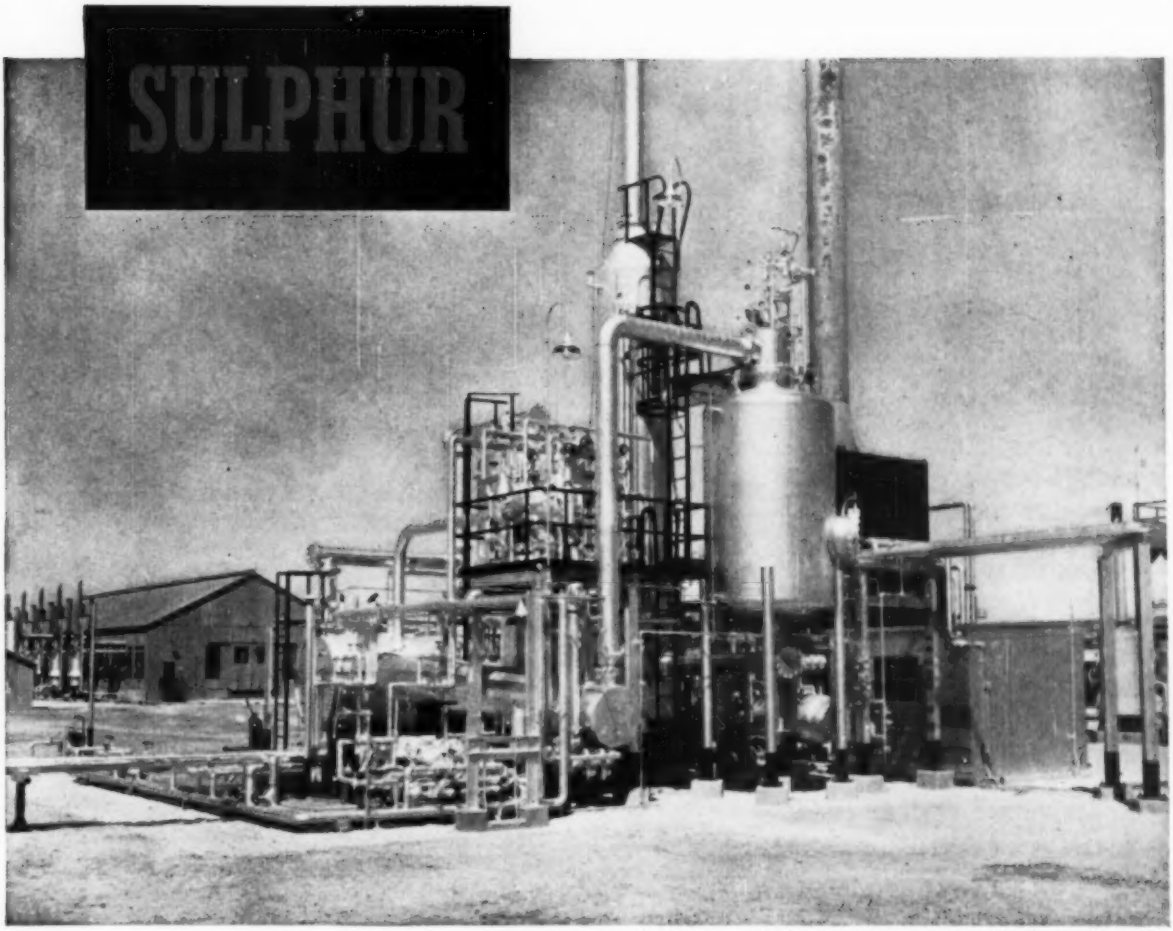
. . . a fine idea to adopt the name "Sherwood Number." The only comment I would make about the approach Sage has taken has to do with nomenclature. I believe Sherwood's own preference has been to use k_c for mass-transfer coefficient expressed in lb.mole/(hr.)(sq.ft.)(lb.mole/cu.ft.) instead of Sage's m.

R. L. PIGFORD
Chairman, Dept. of Chemical Engineering
University of Delaware

. . . enthusiastic support for the suggestion . . . the many people familiar with Tom's outstanding work would be in hearty agreement.

M. C. MOLSTAD
Director, Chemical Department
University of Pennsylvania

(More letters on page 8)



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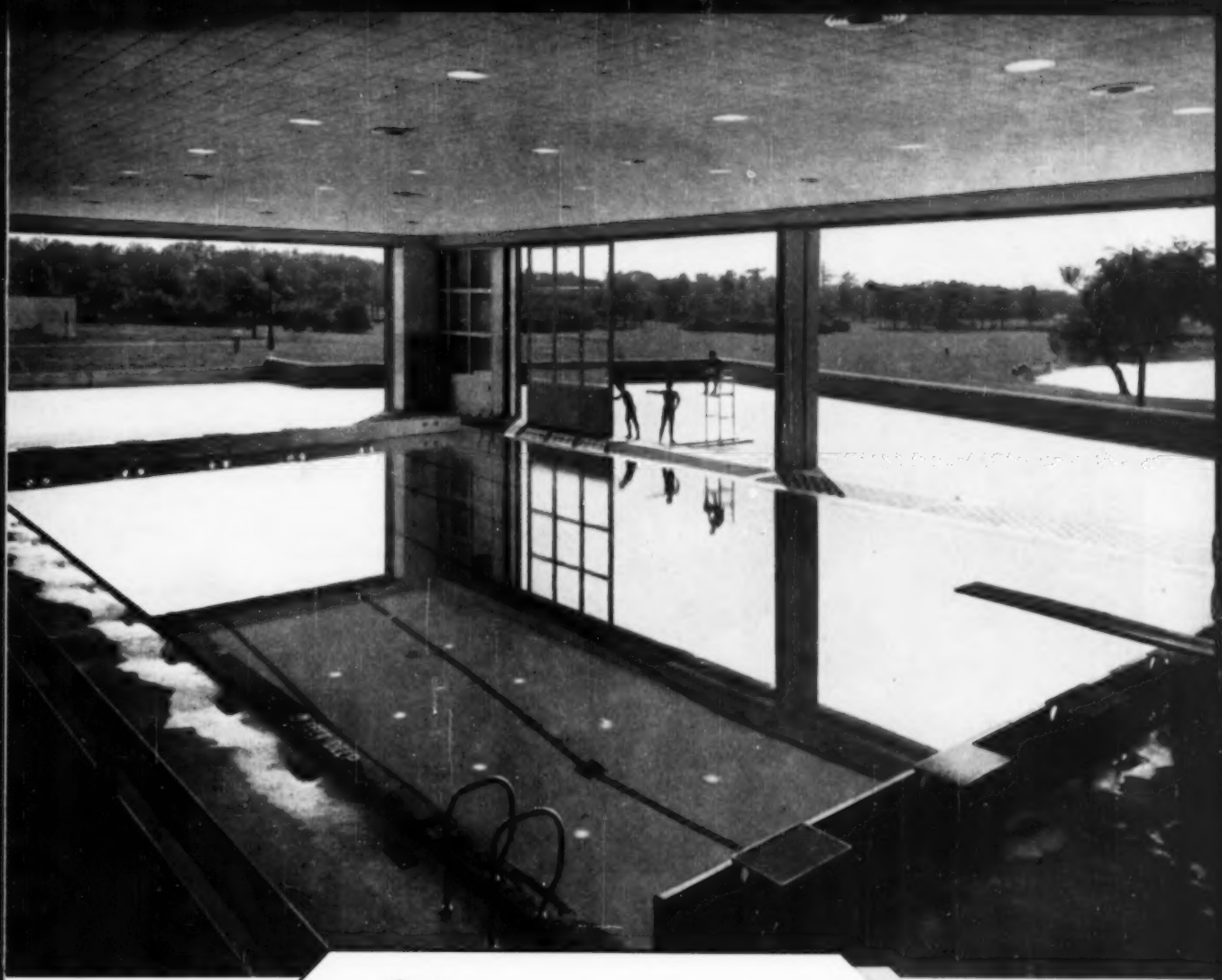

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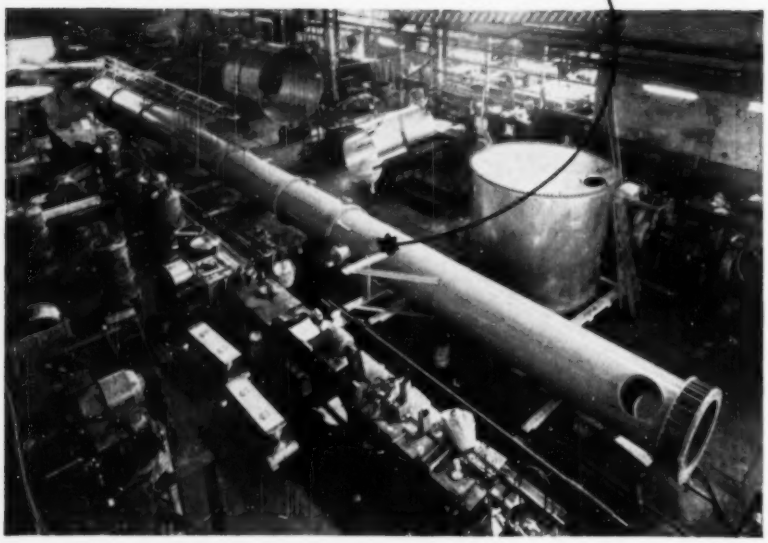

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LETTERS TO THE EDITOR

(*Continued from page 4*)

. . . an excellent idea and I am heartily in favor of it.

E. W. COMINGS

Head, Dept. of Chemical Engineering
Purdue University

. . . desirable . . . .

R. W. MOULTON

Executive Officer of
Chemical Engineering
University of Washington

. . . am highly in favor. . . . Sherwood first mentioned this group in his paper with Gilliland on mass transfer in a wetted-wall column which was published in 1934.

H. F. JOHNSTONE

Director, Dept. of Chemical Engineering
University of Illinois

. . . whether this is used or not, is going to depend upon the individual acceptance by many people. . . . A few workmen in the field using the designation would probably do more toward making it general.

GORDON C. WILLIAMS

Professor and Head, Department
of Chemical Engineering
University of Louisville

. . . this proposal will meet with the approval of all working in the field of mass transfer; in fact no more deserving "godfather" could be found. Hence it is not astonishing to find that the proposal has been made before. Van Krevelen and Hoftijzer (*Rec. Trav. Chim.*, **66**, 49, 1947) in the first paper in their series of "Studies of Gas Absorption" give the name "Sherwood number" to a unit dimension which is identical to Professor Sage's proposal.

In the same paper these authors propose to give the name of "Hatta number" to [another] unit dimension [based on the Schmidt number, the diffusion coefficient, viscosity, and density].

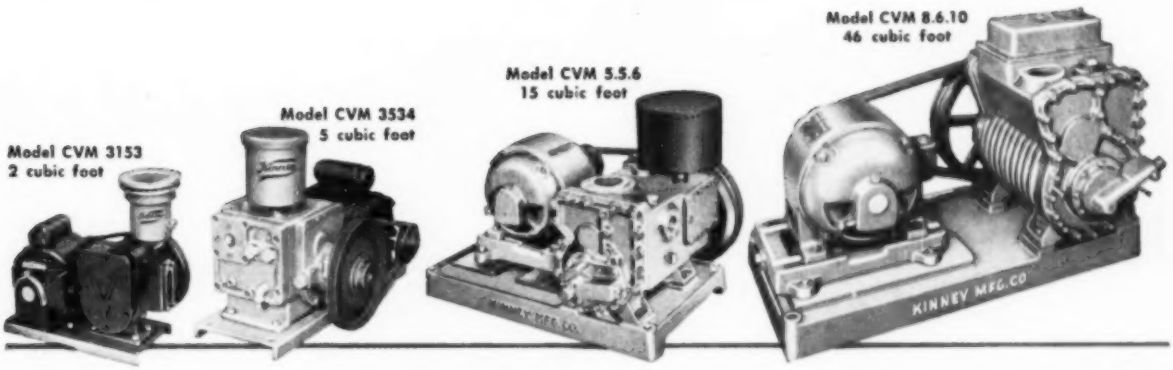
G. W. VAN DER PAS

South Pasadena, Calif.

Much as I agree with Sage in regard to the valuable contributions by Prof. Sherwood, one cannot help but feel that the Sherwood number is similar to Nusselt's number (if we agree that diffusional processes are identical for mass and heat transfer), and wonder whether the introduction of the "transfer" coefficient (as in Nusselt's number) makes the Sherwood number a dimensionless group in the same sense as Reynolds' or Prandtl's. . . .

. . . sooner or later the whole field of dimensionless groups is going to come under closer scrutiny. We who appreciate Sherwood's valuable work, recognize that he deserves the honor suggested. . . . But

(*Continued on page 10*)



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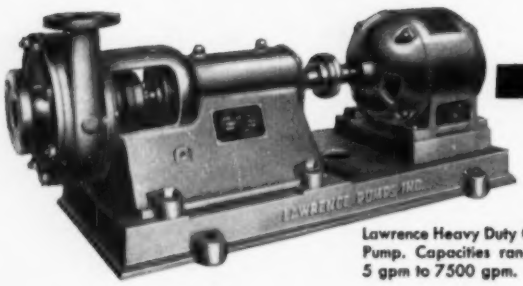

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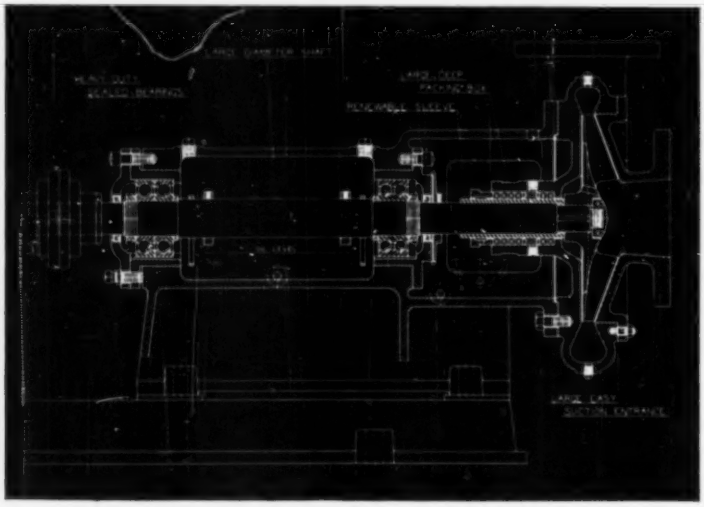

Cross-section of Lawrence Heavy Duty Chemical Pump.

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LETTER TO THE EDITOR

(Continued from page 8)

. . . others [may be] inclined to accuse chemical engineers of surfeiting the literature with dimensionless groups, when few are needed.

. . . many of the groups we now use are simplified when we apply them to gases. By noting that in kinetic theory, viscosity is proportional to $\rho\lambda u_m$ and thermal conductivity to μC_v, we get the equivalent dimensionless groups indicated in the last column of the following tabulation.

Group Name	Group	For Gases
Reynolds	$\rho UL/\mu$	$\left(\frac{U}{u_m}\right)\left(\frac{L}{\lambda_m}\right)$
Prandtl	$C_p\mu/k$	C_p/C_v
Nusselt	hL/k	L/L_t
Stanton	$h/U\rho C_p$	$\left(\frac{\lambda_m}{L_t}\right)\left(\frac{u_m}{U}\right)\left(\frac{C_v}{C_p}\right)$
Peclet	$LU\rho C_p/k$	$\left(\frac{L}{\lambda_m}\right)\left(\frac{U}{u_m}\right)\left(\frac{C_p}{C_v}\right)$
Sherwood	$\frac{mL}{D_p}$	$\left(\frac{m}{u_m}\right)\left(\frac{L}{\lambda_m}\right)$

. . . for gases and gas vapor films, the important dimensionless groups reduce to simple ratios of length, velocity and heat capacity. For gases, the Sherwood number turns out to be much different from the Nusselt number, since m is a "coefficient" having the dimensions of velocity. . . .

There is altogether too much dimensional analysis and it is being carried to extremes. One of my colleagues has remarked (facetiously) that we haven't gone far enough—we should develop groups so that all data result in a single point rather than a curve. I would like to propose that the A.I.Ch.E. appoint a committee to report on the whole question of dimensionless groups and clarify such questions as (*a*) their derivation and meaning and (*b*) when to use them.

J. M. DallaValle

Professor, Chemical Engineering
Georgia Institute of Technology

. . . happy to honor my good friend Tom Sherwood. On the other hand, my personal opinion is that there are now so many named dimensionless groups that one needs a card catalog to keep run of them.

From the point of view of use and understanding, equations are apt to be clarified by expressing the so-called dimensionless groups in terms of the directly measured or sought quantities. The tendency . . . of some to present a paper in which the equations are made up almost exclusively of symbols such as, N_{re}, N_{st}, N_{pe}, N_{nu}, N_{pr}, N_{gr}, and pure numbers, seems to me to constitute a striving for elegance at the expense of clarity.

T. B. Drew

Department of Chemical Engineering
Columbia University

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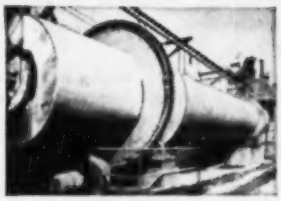

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NOTED AND QUOTED

The Unrealistic Segment

There is a large segment of American industry that has failed to be realistic in its adjustment of salaries and wages of its employed professional engineers. The salaries for beginning engineers have risen at a much faster ratio than have the increments of advancement for qualified engineers of five, ten, and twenty years of service in some companies within this unrealistic industry segment to which I refer. Actually, in some instances the starting salary curves for recent graduates have intersected the average salary curve of men of some years of service and experience within the engineering profession. It is the American industrialists of this negligent segment who furnish bona fide reasons for some union or other group to challenge the administrative competence of the managers concerned.

W. R. Woolrich, President
American Society for Engineering Education

Pinpointing Research

The more specifically one tries to define the practical purpose of a research, the more indefinite becomes its bearing on the important questions of science and the less reason a scientist can find for doing it.

Thomas H. Johnson
Atomic Energy Commission

Brains Not Miracles

Science is not a thing apart nor the scientists a peculiar race unlike the rest of mankind, Shylock's speech could easily be adapted to them. Nor are there any miracles in science—only brains and their application. The miracles come from the fancies of the public relations and advertising departments.

Francis J. Curtis
Society of Chemical Industry
Nottingham, England

Progress

During the past fifty years the population of the country has doubled. Our production, however, has increased to four and three-quarters times what it was at the turn of the century. This has come about largely because we have been able to develop and apply, at the hand of the worker, about four and one-half times as much energy as was available to him in 1900.

S. C. Hollister
Centennial of Engineering

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In addition to these two tubing steels, two other modifications of the basic steel have been produced. CROLOY 16-13-3ELC, a low carbon (.03 max.) grade, is especially suitable for field welding and CROLOY 18-13-3, with higher chromium and molybdenum, is particularly resistant to pitting and wedge or contact corrosion in saline solutions.

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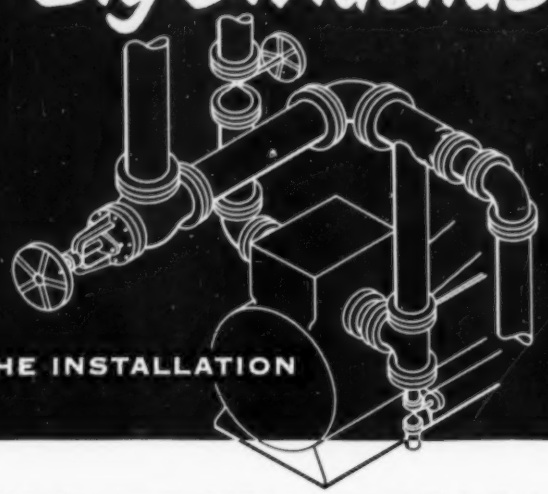
B&W STAINLESS and WELDED TUBES

TA-1753 (H)

Thrifty Valve Buying in 1918 Still Paying Big Dividends



THE INSTALLATION

At the American Crystal Sugar Company's Rocky Ford, Colorado, mill where Crane 12-inch iron body angle valves control carbon dioxide to pumps supplying the gas for carbonation process.

VALVE SERVICE RATINGS

SUITABILITY: *Never failed in 35 years*

FEATURES: *Simplified design—easy to service*

MAINTENANCE COST: *None—Routine care only*

SERVICE LIFE: *Installed 1918—still O.K.*

OPERATING RESULTS: *Dependable CO_2 control*

AVAILABILITY: *Crane catalog item—No. 353*

THE CASE HISTORY

This CO_2 service requires valves of utmost dependability to protect process and equipment from damage. In the event of malfunction or failure of pumps, the valves must assure positive closure every time.

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You can see the ruggedness and serviceability of No. 353 angle valves, but it's what's inside that counts most in their better performance. Choose these valves from the complete family of Crane 125-pound iron body globes and angles. It gives you the widest selection of patterns and types for steam, water, oil, and gas. See your Crane Catalog or your Crane Representative.

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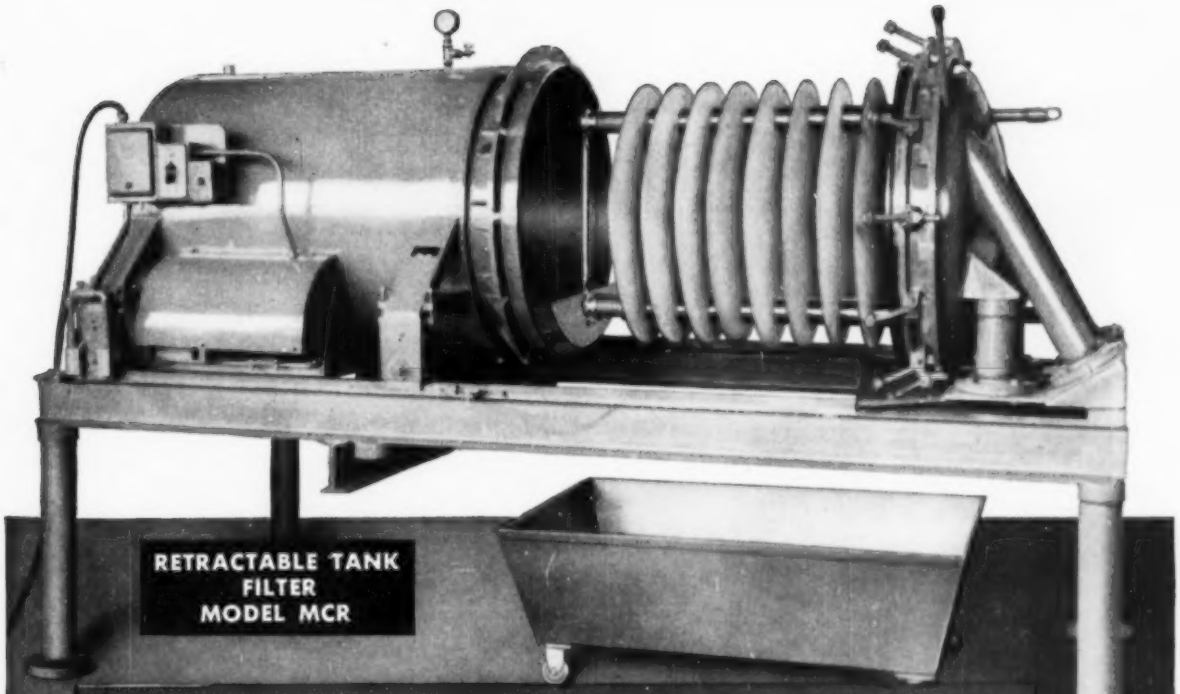

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60 Second opening or closing without disconnecting piping. Available in sizes from 100 to 2000 sq. ft. filtering area.

This new retractable tank model MCR filter opens up a new phase in filtering that will lower the cost materially in many industrial fields.

One movement of a handle releases all head bolts simultaneously, a flip of a switch and the retractable tank moves back, stopping automatically, leaving the plates exposed for hand cleaning. All in less than 60 seconds. Pipe connections are all in the stationary filter head so no disconnecting of piping is necessary. This gives you the fastest action, time-saving, labor-saving tank opening ever engineered in a filter.

Jet spray tubes can be supplied in this filter with automatic breaking head seal for water supply. With the jet spray the cake can be washed off with pressure spray, backwashed, or a combination of jet spray and backwashing employed for cleaning the plates.

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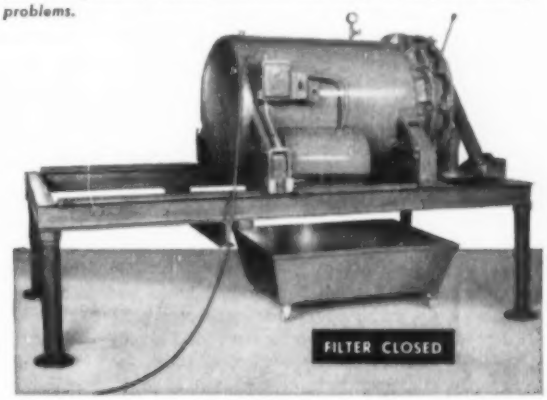
Filter tanks can be supplied in mild steel, stainless steel, or other metals to meet chemical requirements. Tanks can be rubber lined or plastic lined for corrosion resistance. Each filter including valves and piping is engineered to perform the job required.

Write for specific information about this new filter pertaining to your particular product. Personal attention will be given to your filtering problems.



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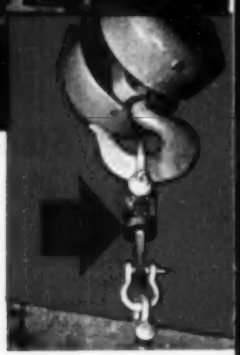
Pfaudler factories are located in Rochester, N. Y.; Elyria, Ohio; Leven, Fife, Scotland; and Schwetzingen, Baden, Germany. Sales offices in all principal cities.

Write for Bulletin 902-L-2 our new general catalog on Pfaudler equipment.



CLOSE-UP showing how the glassed steel discs were connected to crane so as to support entire weight of 5½-ton truck. Below: close-up showing steel discs "glassed" together.

THE PFAUDLER CO. Pfaudler **ROCHESTER 3, N. Y.**

Opinion and comment

ENGINEERS LEAVE HOME—WHY?

Early this year the Research and Development Board, under the chairmanship of the well-known chemical engineer Walter G. Whitman, formerly of Massachusetts Institute of Technology, issued a survey on industrial research and development. The preliminary report was based on statistics gathered from some two thousand firms by the Bureau of Statistics, Department of Labor. Every executive or administrator in the chemical field who works with engineers and research scientists should be familiar with the highly significant conclusions.

Annual research expenditures in recent years were more than three and one-half billion dollars, more than four times the yearly total at the beginning of World War II. The average research cost for each industrial research engineer or scientist in 1951 was $22,100, and the average cost for each worker in research when all employees and supporting personnel were considered was $8,900.

This all adds up to a major investment in research by industry and makes less familiar figures in the report of particular interest. The survey revealed an annual separation rate of 16.4 for every hundred scientists and engineers in industry. With some gratification we note that the average for the chemical field was lower, but unfortunately not by any great amount. The average was 14 per cent although some companies employing research staffs of 250 to 499 persons had much higher separation rates, in one case 27 per cent. Since the average cost of each research engineer and scientist in the chemical field was $16,500 each year, so many separations represented a major financial loss. The time has come to exercise research intelligence to discover why 16 to 27 per cent of the country's best brains changed jobs every year.

Military needs were not the whole answer, for the same study revealed that although 25 per cent of the research engineers and scientists considered were in the categories most liable for military service, 19 per cent in the Reserves and National Guard and 6 per cent classified 1A or 2A, still only three of every hundred were called up in 1951. The demands for military service caused less than one fifth of the separations.

That the burgeoning defense industries caused some of the separations in 1951 was indicated by the aircraft industry average of 20.8 per cent. Since the Korean hostilities there had been tremendous expansion in this field and resulting increased competition for engineers. But the petroleum refining field, which also had expansion competition, had an annual separation of only 8.8 per cent. Why?

If engineers leave home because of finances, then research directors and company executives might well keep in mind their dollar investment in every engineer working for them. The fact that every man who walks out represents a loss ranging from $8,900 to $22,100 warrants a generous attitude toward raises and remuneration. Considering the care that is lavished on machinery and new equipment and the investment in statistical and operational research, executives might profitably inaugurate an intense psychological investigation into the causes for dissatisfaction among engineers and research personnel. Whenever an engineer is lost to another company for a few hundred dollars a year, for working conditions, for personality difficulties, or for any other reason, it calls for scrutiny of personnel relations and a rigid inspection of salary levels. Through an all-out effort to keep engineers happy at home, companies will not only prevent loss of invested capital, but, almost with certainty, they will realize more in engineering results from the research investment.

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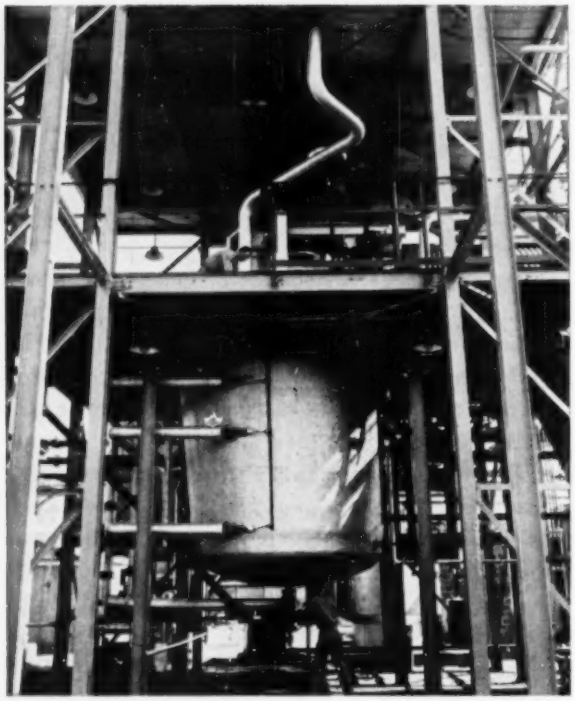

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The Fluidized-Bed Sulfate Roasting of Nonferrous Metals

Frank M. Stephens, Jr. Battelle Memorial Institute, Columbus, Ohio

The possibility of selectively sulfating individual components in ores long has interested the extractive metallurgist. In the laboratory it has been demonstrated that many sulfide and oxide minerals can be converted readily to water-soluble sulfates and, with careful temperature control, these conversions become quite selective. However, in actual practice in operating plants it has been difficult to secure results comparable with those obtained in the laboratory.

The primary reasons for failure of most of the large-scale sulfating operations has been the inability to maintain proper temperature and atmosphere control in the furnacing equipment. All too frequently, hot spots have developed in the charge or within the individual ore particles and this has caused decomposition of the valuable metal sulfates.

Within the past few years a new type of roasting equipment has become available. This is the fluidized-bed reactor, which has found a wide use in the petroleum field and is becoming more widely used in the chemical and metallurgical industries. This equipment has revived interest in selective sulfating because of the ease with which the roasting atmosphere and temperature can be controlled.

It is the purpose of this paper to describe a series of tests which has been made with a fluidized-bed reactor in which copper and cobalt ores have been roasted to yield soluble sulfates.

After graduation from the Colorado School of Mines with the degree of E. Met., F. M. Stephens, Jr., worked at Battelle Memorial Institute, Columbus, Ohio. As chief of the Extractive Metallurgy Division of Battelle, he supervised research on new processes for the extraction of metals from low-grade ores. This year he received the award of the *Journal of Metals* for his paper "The Reduction-Oxidation Process for the Treatment of Low-Grade Iron Ores."

Sulfate Roasting

Several basic principles concerning sulfate roasting should be considered. These include the theoretical decomposition points of metal sulfates, the effect of the partial pressure of sulfur dioxide in the atmosphere on the decomposition points of metal sulfates, and the theoretical selectivity of the sulfating reactions under ideal conditions.

Table 1 shows the commonly recorded (*1*) values for the decomposition points of metal sulfates under a moving current of air. A plot (*2,3*) of the partial pressure of sulfur dioxide against temperature (Fig. 1) for the general reaction

$$2MSO_4 \rightarrow 2MO + 2SO_2 + O_2$$

Table 1.—Decomposition of Anhydrous Metallic Sulfates*

Metallic Sulfate	Temp. at Beginning of Decomposition, ° C.	Temp. of Energetic Decomposition, ° C.	Products of Decomposition,
$FeSO_4$	167	480	Fe_2O_3, $2SO_3$
$Fe_2O_3.2SO_3$	492	560	Fe_2O_3
$Al_2(SO_4)_3$	590	639	Al_2O_3
$PbSO_4$	637	705	$6PbO.5SO_3$
$CuSO_4$	653	670	$2CuO.SO_3$
$MnSO_4$	699	790	Mn_3O_4
$ZnSO_4$	702	720	$3ZnO.2SO_3$
$2CuO.SO_3$	702	736	CuO
$NiSO_4$	702	764	NiO
$CoSO_4$	720	770	CoO
$3ZnO.2SO_3$	755	767	ZnO
$MgSO_4$	890	972	MgO
Ag_2SO_4	917	925	Ag
$6PbO.5SO_3$	952	962	$2PbO.SO_3$(?)
$CaSO_4$	1200	...	CaO

* Decomposition under moving current of air.

shows that the observed points where sulfate decomposition begins are approximately the points where the partial pressure of SO_2 is equal to 7 to 15 mm. of Hg and that the reaction becomes energetic at a point where the partial pressure of SO_2 equals 30 to 80 mm. of Hg.

Because both these values lie in the flat portions of the curves, it is easy to see why there is considerable overlap in the recorded temperature values at which sulfate decomposition supposedly occurs, and why, in normal roasting equipment, small variations in temperature materially affect the end products.

However, if the roasting atmosphere is controlled to maintain a relatively high partial pressure of SO_2, say 50 mm. Hg, then the actual decomposition points move into the area of the curve where the lines become more vertical. With this condition, temperature control becomes less critical, although still important, and the chances of obtaining selective decomposition are much improved.

For example, as shown in Figure 1, if the partial pressure of SO_2 in the roasting atmosphere is zero and the roasting temperature is 750° C., the $NiSO_4$ and $CoSO_4$ will decompose at appreciable rates and little selectivity can be expected. However, if the partial pressure of SO_2 in the roasting atmosphere is 50 mm. Hg and the temperature is 800° C., then $NiSO_4$ should decompose, but $CoSO_4$ should remain stable and a selective roast could be obtained.

In most metallurgical problems the degree of selectivity required is not so great as that sought in the previous example. Normally the main problem is to produce a soluble sulfate of some metal such as copper or cobalt while keeping the iron insoluble. Although the starting material for such a separation may be an oxide ore which is to be treated with SO_2 and air, it is more often a sulfide ore which is to be roasted with air alone.

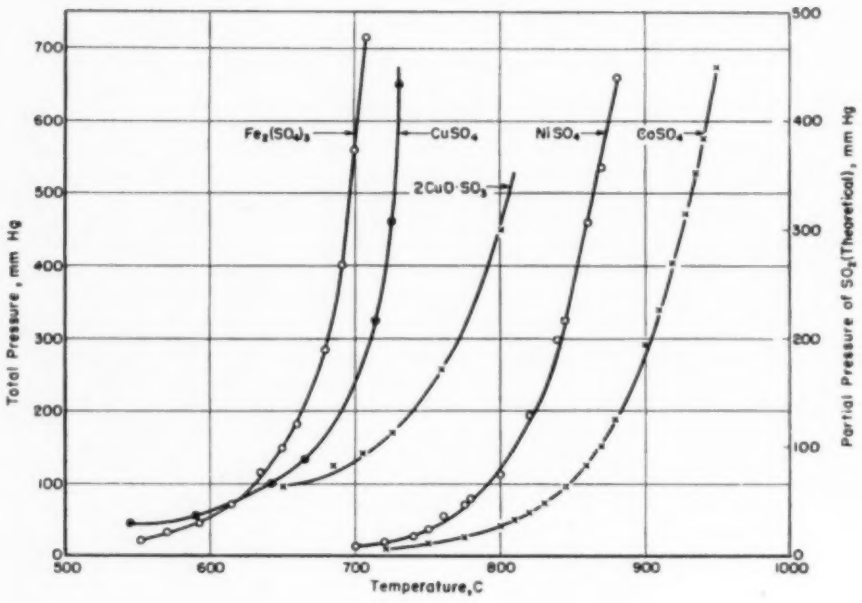

Fig. 1. Vapor pressure of metal sulfates as function of temperature.

FLUIDIZED-BED ROASTING EQUIPMENT

In the actual test work on the development of this process, three types of fluidizer have been used. The first is a 4-in. diam. glass unit used in preliminary tests to obtain data on space velocities, segregation, and dust carry-over. The second fluidized-bed reactor was a 5-in. diam., externally heated steel unit used in the preliminary test work to obtain data on the optimum temperatures and gas compositions. The third reactor was the 2-ft.-diam. unit shown in Figure 2. This unit was used for the autogenous roasting of tonnage samples to obtain engineering data for plant construction.

The 2-ft. reactor is equipped with high-pressure gas burners to bring the initial charge up to reaction temperature. The air supply comes from a compressed-air line and is metered through rotameters. The unit is lined with a rammed-sillimanite lining, and the air-distribution plate is made from a castable refractory backed up with a steel plate. The ore concentrates can be fed to the reactor in either a wet or a dry condition by using either Moyno pumps or air-injection feeders. The pressure drop across the bed is measured by a series of four manometers, and the temperatures at four positions are recorded on a four-point Micromax recorder. The dust-collection system normally consists of one or more cyclones, followed by a small twin-tube Cottrell-type collector. Material is discharged from this reactor by means of a top-overflow discharge pipe controlled with a star-gate draw.

TREATMENT OF COPPER-BEARING MATERIALS

Sulfate roasting of copper-bearing materials usually is undertaken for one of two reasons—the recovery of copper as a valuable material or the removal of copper as an impurity. Copper ores and concentrates containing up to 40% Cu fall in the first group, while iron ores with one to two % Cu are examples of the latter group.

In the treatment of these ores and concentrates, both sulfide and oxide minerals must be considered. The most important sulfide minerals are chalcocite, Cu_2S, and chalcopyrite, $CuFeS_2$. The major oxide copper minerals are azurite, $2CuCO_3 \cdot Cu(OH)_2$, chrysocolla, $CuO \cdot SiO_2 \cdot 2H_2O$, and malachite, $CuCO_3 \cdot Cu(OH)_2$. In roasting the sulfide materials, the following reactions occur:

$$2Cu_2S + 5O_2 \rightarrow 2CuSO_4 + 2CuO,$$

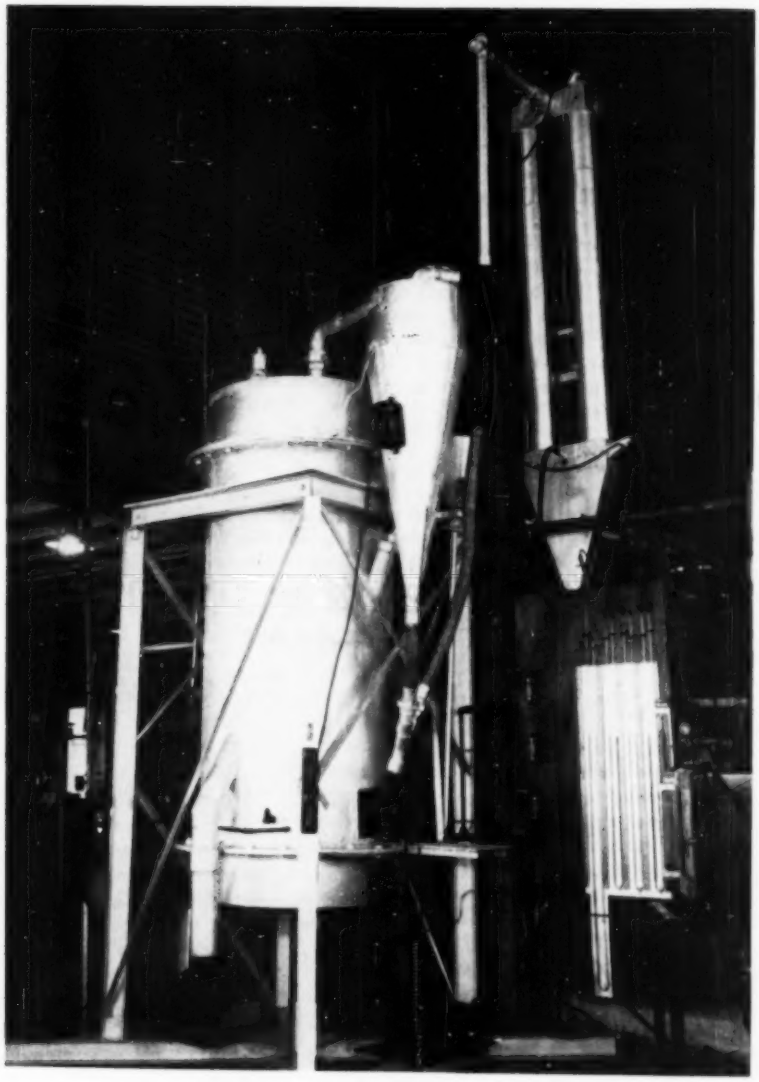

Fig. 2. Two-foot diameter fluidized-bed reactor.

$4CuFeS_2 + 15O_2 \rightarrow 4CuSO_4 + 2Fe_2O_3 + 4SO_2$.

In the roasting of the oxide minerals, where SO_2 and air are used, the following reaction applies after dehydration and decomposition of the hydroxides and carbonates:

$2CuO + 2SO_2 + O_2 \rightarrow 2CuSO_4$.

The source of SO_2 for the reaction with CuO is unimportant. It can come from the burning of sulfides such as FeS_2, which are mixed with the ore, or it can be added to the inlet gas going to the reactor.

In the evaluation of the fluidized-bed system as a means of carrying out sulfating roasts on copper-bearing materials, three variables have been checked. These are air flows, temperatures, and gas compositions. The effect of each of these may be summarized briefly as follows.

Effect of Air Flow

The amount of air used as a fluidizing medium in the test work was recorded as a multiple of the air theoretically required to convert all the copper to $CuSO_4$, all of the iron to Fe_2O_3, and all excess sulfur to SO_2. Table 2 shows what effect varying this air flow has on producing soluble copper sulfate.

Table 2.

Roasting Temp., ° C.	Theoretical Air Flow	Water-Soluble Copper, %
600	0.7x	78
600	1.2x	97
600	2.0x	94
600	2.3x	91

These data indicate that optimum copper sulfate formation requires theoretical or slightly higher air flows and that lack of sufficient air is more detrimental than is an excess.

Effect of Temperature

Tests were conducted with various types of ores and concentrates to demonstrate the effect of temperature on the formation of copper sulfate. In these same tests, the effect of temperature on the decomposition of iron sulfate was recorded. Table 3 summarizes the results of this work.

Table 3.

Roasting Temp., ° C.	Water Solubility Cu, %	Water Solubility Fe, %
600	94	5.0
650	92	2.1
700	76	1.4

These data indicate that roasting temperatures of 650° C. are probably the optimum, if high copper and low iron solubilities are desirable.

Effect of Reactor-Gas Composition

Tests to determine the effect of the compositions of the reactor gases on the formation of water-soluble copper sulfate have been limited to only the range of gas compositions normally encountered in roasting sulfides, namely, 6 to 15% SO_2 and 0 to 10% O_2.

These studies show that the best results are achieved when a reactor gas containing about 8% SO_2; and 4% O_2 is used. When the SO_2 content drops lower than this amount, the copper sulfate becomes unstable and begins to decompose unless the temperature is lowered. However, lowering the temperature is undesirable, because then the amount of soluble iron increases. If the SO_2 content exceeds 8%, the free-oxygen content drops and insufficient oxygen is available to form the desired sulfates.

TREATMENT OF COBALTIFEROUS PYRITE

Many pyrite deposits contain small amounts of cobalt which are probably present in solid solution. This cobalt can be converted to a water-soluble form by roasting the pyrite in a fluidized-bed reactor. The probable reaction is:

$CoS + 2O_2 \rightarrow CoSO_4$.

As is the case with copper, air flow, temperature, and reactor-gas composi-

tion are important variables. Test work has shown that the air flow must be 1.5 to 2.0 times theoretical to obtain good cobalt solubilities. Typical air-flow data are as shown in Table 4.

Table 4.

Temp., ° C.	Theoretical Air Flow	Water-Soluble Co, %
650	0.5x	9
650	1.0x	18
650	2.0x	87

The most effective temperature for converting cobalt to soluble form is 650° C. Table 5 shows typical variations of solubility as a function of temperature.

Table 5.

Temp., ° C.	Theoretical Air Flow	Water-Soluble Co, %	Water-Soluble Fe, %
600	2.0x	75	1.5
650	2.0x	87	1.0
700	2.0x	14	0.3

As is the case with copper ores, optimum solubilities of cobalt are obtained when the roaster gas contains about 8% SO_2 and 4% O_2.

FACTORS AFFECTING FLUIDIZATION

Many other factors affect the treatment of ores in a fluidized-bed system. These include both chemical and physical conditions, such as reaction rates, side reactions, heat balances, particle sizes, dust carry-over, and short-circuiting.

In other fields, such as catalytic cracking, where fluidized-bed reactors are widely used, most of these variables are controlled easily. However, in the roasting of ores, not all these variables can be controlled because they are inherent with the material being treated. When ores are roasted, it is the solid charge in the reactor as well as the gaseous phase which undergoes a chemical change. It is not uncommon for the solids to undergo changes in density, chemical composition, particle size, and even physical state during the reaction.

It is beyond the scope of this paper to examine each of these factors critically, but their mention here is essential because, in many cases, they are the factors which determine whether the basic reactions can be utilized in a commercial plant.

Pilot-plant test work carried out on a continuous basis has indicated that, so far as the sulfate roasting of copper and cobalt minerals is concerned, these variables can be handled with sufficient ease to make the process commercially feasible.

Summary

The ease with which temperatures and atmospheres can be controlled in the fluidized-bed reactor makes this reactor ideally suited to selective sulfate roasting, a process which has not been used widely because it cannot be controlled satisfactorily in other types of roasting equipment.

This paper describes test work which has been carried out through a pilot-plant scale and has shown that the fluiuized-bed reactor can be used successfully for treating copper and cobalt ores to produce water-soluble copper and cobalt sulfates while retaining the iron in insoluble-oxide form.

Acknowledgment

Much of the test work was sponsored by Frobisher, Limited, and the author wishes to express his appreciation to this company for the use of its data, and to F. R. Archibald of Frobisher, Limited, for his encouragement during the early stages of the test work.

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Discussion

J. W. Colton (Scientific Design Co., New York, N. Y.): Did you state the particle size used in these experiments?

F. M. Stephens, Jr.: The data discussed was taken from tests run on material which was about 98%-200 mesh. However, we have run tests on everything from ¼ in. to material which is 90%-325 mesh.

J. W. Colton: Did you find any difficulty with conducting the chemical reactions on large particles?

F. M. Stephens: That would depend somewhat on the ore itself. In the case of pyrite ores containing cobalt, particle size does not materially affect the rate of chemical reaction. If you are treating such material as pyrrhotite containing nickel, then the size becomes quite important.

W. E. Lobo (M. W. Kellogg Co., New York, N. Y.): You stated that you studied three variables, the last being the concentration of oxygen or sulfur dioxide in the outgases and I don't quite see how you made that study. It seems to me you were studying the amount of air used and the temperature, and the other would come as it would.

F. M. Stephens: Data on the slides do not show the study of gas composition. However, it is possible to adjust the gas composition by the addition of extra sulfur dioxide in your inlet gases.

Raphael Katzen (Vulcan Engineering Div., Cincinnati, Ohio): You spoke of a bed running about 2 ft. in diam. by about 2½ ft. deep. Then you indicated later that you ran some sizable variations in air flow and temperature. Did that cause you to make any adjustments in the space velocity or did you just take the space velocity as it came?

F. M. Stephens: Space velocity, of course, is a problem. We've operated over a series of space velocities ranging from about ½ ft./sec. up to about 1.2 ft./sec. with this material. Our problem, of course, is one of dust carryover.

M. P. Sweeney (United Engineers, Philadelphia, Pa.): Did you encounter any conditions of stickiness in the bed? Were you able to fluidize it satisfactorily? And did you make experiments which successfully separated cobalt and nickel?

F. M. Stephens: In the process as finally developed there is no problem of sticking. However, we have had reactors where we had to go in with a chisel and dig out the bed. If the temperature is not controlled when treating some ores you will encounter sticking. We have never actually worked on the selective separation of nickel and cobalt.

E. J. Roberts (The Dorr Co., Stamford, Conn.): I think I can answer Dr. Katzen's question. What you do is to hold the air rate constant and change the solid feed rate to vary the per cent of excess air. Is that not what you did?

F. M. Stephens, Jr.: That is right.

C. B. Bare (Bethlehem Steel Co., Lebanon, Pa.): What do you figure is the holdup time of the solids in the furance?

F. M. Stephens, Jr.: In this case it amounts to from 2 to 2½ hr. in the 2-ft. reactor.

C. R. Bare: And what is the rate at which you fed the large reactor when operation was at maximum input?

F. M. Stephens: When we are operating with material essentially 200 mesh the 2-ft. reactor has a capacity of about 33 to 50 lb./sq.ft./hr. The capacity, however, varies with the particle size of the material fed to the reactor.

Presented at A.I.Ch.E. Biloxi meeting.

Agitation of Viscous Solid-Liquid Suspensions

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The agitation of a liquid system is primarily a problem of fluid dynamics. The similarity to flow in pipes is striknig; the now-familiar power-function correlation, for example, is directly analogous to a Fanning chart, employing as its independent variable a form of the Reynolds number. Some fifteen years ago White and Sumerford (*14*) published a power-function plot for flat paddles which is still in use (*9*). This correlation showed a transition point at a Reynolds number of about 40; to the left of this point, the line was drawn with a slope of negative one and the movement of the liquid was characterized as laminar or viscous. Although White and Sumerford presented no data to substantiate the laminar line, probably no one seriously doubted that such a region existed and that, by analogy to flow in pipes, the action in a liquid characterized by viscous agitation would be quite different from that exhibited in turbulent agitation.

Contemporary with and subsequent to White's early publications, much fruitful effort has been devoted to quantitative evaluation of both the power and the functional performance† of agitator impellers. Most of this work has been directed toward the turbulent range, and the few quantitative studies of the viscous region have been limited to power observations. Several investigators (*1, 4, 8, 10*) reported power data for impellers of specific design and proportion operating in the viscous regime, and O'Connell and Mack (*8*) succeeded in generalizing the power data of this regime for two-, four-, and six-blade flat paddles in baffled tanks. Rushton, Costich, and Everett (*10*) pointed out that below an agitation Reynolds number of 10 the action apparently is always laminar, and Mack and Uhl (*7*) demonstrated that viscous motion can occur at Reynolds numbers as great as 500 if the impeller has thin blades. Two papers (*4, 10*) reported that the laminar-region power requirements of turbines is virtually unaffected by baffling. No data for the functional performance of any impeller in the viscous region have been published, however, and no author has questioned the basic validity of the viscous section of the White-Sumerford generalized power correlation for unbaffled paddles or proposed a substitute therefor. In view of the increasing frequency of agitation problems (for example, in the high-polymer industry) that inescapably involve the viscous region, a region in which baffles often should be avoided, the importance of developing such missing information is clear.

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† Functional performance refers to the action of agitator in promoting some physical or chemical change, e.g., heat transfer or solution homogeneity, within the agitated mass.

Additional data of Table 5 are on file (Document 4056) with the A.D.I. Auxiliary Publications Project, Photoduplication Service, Library of Congress, Washington 25, D. C. A copy is obtainable by remitting $1.25 for photoprints, or $1.25 for microfilm.

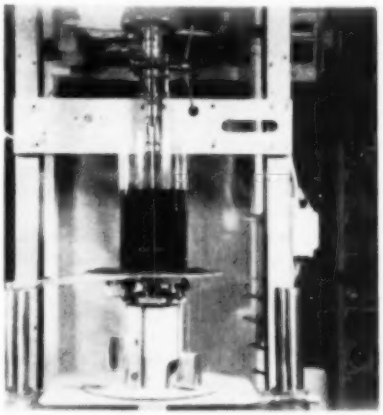

Fig. 1. Drive and dynamometer.

The investigation reported here was an initial exploration of viscous agitation as applied to the suspension of insoluble solids in a liquid and of the power requirements of unbaffled flat paddles in the viscous region. Its purpose was twofold: (1) to determine in the viscous region the power requirements of two-blade flat paddles in an unbaffled tank over the complete range of geometrical proportions encountered in the field, and to prepare a generalized power-function chart for these data which would either confirm or replace the viscous-region portion of the White-Sumerford chart as a reliable design implement; (2) to observe the action of flat paddles in high-viscosity solid-liquid suspensions and to induce from such observation whatever helpful generalizations are possible.

Experimental Facilities and Procedure

A flexible agitator-drive system and a torque-table dynamometer were patterned after those of Cooper and co-workers (2). The transmission included a 5-hp. motorized Reeves variable-speed unit and a Delta drill-press head, but it differed from its prototype in that a Turner Uni-drive gear box was substituted for the step-cone pulleys. The gear box had a ninefold range of output speeds in seven increments for a given input; in series with the Reeves drive, it provided the drill-press spindle with an infinitely variable thirty fold range of speed. Thus, with only two pairs of sheaves for the V-belt connection between the gear box and the drill-press head an output range of several hundred fold is possible. Figure 1 shows the drive and dynamometer.

The agitation vessels used were straight cylindrical Pyrex tanks 5.6, 8.2, 11.4, and 17.6 in. in diam. (D), respectively, and 20 in. high. The tanks were unbaffled and their bottoms were substantially flat and filleted at the wall. The impellers were simple two-blade flat paddles made from 12- or 18-gauge half-hard sheet brass. Blade diameters (L) ranged from 1.44 to 15.75 in. Blade widths (W) were so selected as to provide a range of values of W/L between 0.12 and 1.0, the limits commonly encountered

in practice. With the agitators and tanks used, a wide span of D/L ratios was possible; values actually used in the investigation of power requirements ranged from 1.1 to 5.6. The liquid depth (Z) usually was maintained equal to the tank diameter, but in a few runs the depth ratio (Z/D) was varied from 0.5 to 1.4.

For all except the smallest paddles, interchangeable blades were used with a slotted hub 1 in. in diam. attached to a 0.5-in. shaft. If the blade diameter was less than 4 in., however, the hub caused the agitator to consume abnormal power.† Agitators less than 4 in. in diam., therefore, were made by soldering the blade directly to a ⅜-in. shaft.

The liquids used were prepared by diluting corn syrup with water. Since it was desired to keep the agitation unmistakably in the viscous range and to observe the distribution of suspended solids at approximately the same Reynolds numbers in all sizes of tanks, the viscosity employed in each tank during the exploration of suspending action was so selected that the smallest paddle used ($D/L = 4$) could apply at least 10 hp./1,000 gal. without exceeding a Reynolds number of 10. For the power observations the viscosity range was extended to provide a thousand fold variation of Reynolds number within the viscous region. The solutions used ranged from 3,800 to 92,000 centipoises in absolute viscosity. With these viscosities, the agitator speeds investigated resulted in only slight vortex formation; in no case did the vortex reach the impeller. The densities of the solutions lay between 83 and 88 lb./cu.ft. Viscosities over a range of temperatures observed during the tests were measured by means of a Brookfield viscometer, and densities were determined by weight of a volume of the syrup measured in a graduated cylinder.

The solids used were silica sand and a feldspathic material in the form of broken cubes. The density of the particles, determined pycnometrically, was 165.5 lb./cu.ft. for sand and 161.7 lb./cu.ft. for nepheline syenite. Several fractions of closely sized particles were prepared to control the settling velocity within the same order of magnitude for all solutions and to prevent a spread of settling rates within any one solution. The particle sizes used were between 0.028 and 0.056 in., corresponding to settling velocities in the range 1.8 to 3.7×10^{-4} ft./sec. Solids fractionation was accomplished by sieving followed by water elutriation. Enough solids were added to a given tank of syrup to make a 2% suspension by weight.

Power data were taken in the manner described by Hixson and Luedeke (*5*). The temperature of the syrup in the zone near the impeller was observed each time the dynamometer was balanced, and the viscosity recorded was the value corresponding to this temperature. The agitator speed was measured by a hand tachometer accurate to 0.5 rev./min. The sensitivity of the dynamometer, about 1 g., was adequate, since the load was never less than 9 g. and usually greater than 100.

† Hub interference is much more serious in the viscous range than in the turbulent.

It was originally planned to characterize the degree of uniformity of suspension effected by a given impeller by the Hixson-Tenney mixing index (*6*). It soon became apparent, however, that a representative grab sample would be extremely difficult to obtain because of the adherence of solution to the sampler and also because of the pronounced stream lines around the sampler. Although an accurate sampling technique doubtlessly can be devised, it was decided to conduct this initial investigation on the basis of visual observation in order to gain rapidly a qualitative idea of the design variables important in the specification of paddle agitators for solid-liquid suspensions. The agitation was judged to be successful, therefore, if the agitator was able to suspend all the solids from their initial position of rest on the bottom of the tank. This condition was termed, for convenience, "complete suspension." It was found, incidentally, that with the low-settling velocities involved, when complete suspension was obtained the suspension also was substantially uniform. (The portion of liquid nearest the surface was always devoid of solids.)

In the investigation of degree of agitation the procedure was as follows:

A tank containing a desired depth of liquid of appropriate viscosity was centered on the dynamometer and beneath the drill-press head. The solids were added and were given time to settle. A selected paddle was then placed in the solution (with care to avoid excessive entrainment of air bubbles) and was connected to the drill-press spindle. The agitator was started at a low speed and the suspension was observed at 5-min. intervals until its state appeared to be steady. After measurement of the agitator speed and power, description of the suspension, and record of the duration of the transient state, the agitator speed was increased to a new value and the process was repeated. The interval between a speed so low that the solids were rolled gently about the tank bottom without being suspended and one equivalent to a power input of at least 10 hp./1,000 gal. was spanned by a sufficient number of properly spaced steps (four to eight, usually) to allow the approximate evaluation of the minimum speed for complete suspension. When this had been done, the impeller was removed and the suspension was allowed to resettle before the next paddle was tested. In the solids-suspension tests, all the paddles used had the same proportions ($W/L = 0.17$), and the paddle clearance (S) above the tank bottom and the liquid depth were maintained proportional to tank diameter ($S/D = 0.1$, $Z/D = 1$).

Power Requirements in Viscous Agitation

Since the publications of White and his co-workers (*12-14*), most investigators of agitator power have presented their results in terms of dimensionless groups of the variables involved. If surface effects are negligible, the power requirements of a family of geometrically similar impellers may be correlated by a form of the Reynolds number, $N_{Re} = L^2 n\rho/\mu$, and one of two power functions, $\phi_\rho = g_c P/(L^5 \rho n^3)$ and $\phi_\mu = g_c P/(L^3 \mu n^2)$, where

g_c = gravitational conversion factor
L = impeller diameter (tip-to-tip blade span)
n = rotational speed of impeller
N_{Re} = agitation Reynolds number = $L^2 n\rho/\mu$
P = power delivered by impeller
μ = absolute viscosity of agitated liquid
ρ = density of agitated liquid
ϕ_μ = power function involving viscosity = $g_c P/(L^3 \mu n^2)$
ϕ_ρ = power function involving density = $g_c P/(L^5 \rho n^3)$

Choice of the form of the power function is optional, since

$$\phi_\mu = \phi_\rho \cdot N_{Re}$$

White and Brenner (*11*) eliminated the necessity for a different power function plot for each set of proportions employed in the design of a flat paddle and its enveloping tank. They used as modifiers to the power function the simple shape factors, each raised to an empirical power assumed to be constant, that describes the significant geometry of the paddle and its surroundings in terms of the paddle diameter. Combination of the power function and the shape factors gave the compact ordinate quantities

$$\frac{g_c P}{L^{(5-a-b-c)} D^a W^b Z^c \rho n^3}$$

and

$$\frac{g_c P}{L^{(3-a-b-c)} D^a W^b Z^c \mu n^2}$$

for correlation against the Reynolds number.

It is well established (*1, 4, 10*) that the simple power function (without shape factors) and Reynolds number will correlate the data for a family of geometrically similar models even if a change from turbulent to Poiseuille flow occurs. This should be expected, since a change in the exponential relationship of all the correlating factors would in this simplified case result only in a change of slope and intercept of the line. A power function combined with a set of shape factors, on the other hand, should not be expected to correlate data successfully past a critical region and into a new flow regime, since any change in the exponential relationship would be reflected in a change in shape factor exponents and hence in the correlating

TABLE 1.—EFFECT OF PADDLE DIAMETER ON POWER

$W = 1.05$ in., $D = 11.4$ in., $Z = 11.2$ in., $\rho = 87.0$ lb./cu.ft., $\mu = 8{,}300$ centipoises

Paddle Diameter in.	Paddle Speed, rev./min.	Paddle Power, ft.-lb/min.	Reynolds Number	$\phi_a \cdot \left(\frac{L}{W}\right)^{0.5}$
8.46	53	140	6.84	140
	76	283	9.81	137
	99	492	12.78	144
	130	884	16.76	147
6.34	77	121	5.58	118
	139	427	10.06	128
	209	996	15.14	132
	328	2670	23.75	143
4.75	173	294	7.02	116
	268	739	10.89	122
	392	1660	15.87	128
	489	2770	19.85	136
3.16	111	68.4	2.43	123
	242	307	5.00	130
	398	648	7.16	134
	6.3	1610	11.04	140

TABLE 2.—EFFECT OF PADDLE WIDTH ON POWER

$L = 6.34$ in., $D = 11.4$ in., $Z = 11.2$ in., $\rho = 87.7$ lb./cu.ft., $\mu = 8{,}800$ centipoises

Paddle Width, in.	Paddle Speed, rev./min.	Paddle Power, ft.-lb./min.	Reynolds Number	$\phi_a \cdot \left(\frac{L}{W}\right)^{0.5}$
1.01	56	63.7	3.83	122
	120	320	8.20	122
	182	772	12.4	130
	260	1630	17.8	134
1.59	56	81.0	3.82	114
	106	301	7.24	119
	162	740	11.1	124
	206	1235	14.1	129
2.11	37	38.2	2.53	108
	71	147	4.85	113
	95	272	6.48	116
	134	562	9.15	121
	339	4450	23.1	150
3.17	37	47.5	2.53	112
	69	169	4.71	114
	95	330	6.49	118
	133	682	9.08	124

group itself. As a matter of fact, such a shift in relationship has been demonstrated for baffled tanks by O'Connell and Mack (*8*). Thus the White correlation in the viscous region is illogical and therefore entirely unjustified in the absence of supporting data; if it were correct, the circumstance would be fortuitous. A recent graphical comparison (*10*) of it with data of other investigators for a paddle of particular proportions is not helpful in evaluating its accuracy since the White generalized ordinate was plotted as a power function for specific impellers without explanation of the method.

In order to establish a correlating function for viscous power data, the usual procedure of investigating one variable at a time was followed. Data for the effect of paddle diameter and paddle width are shown in Tables 1 and 2 and in Figures 2 and 3. A cross plot of the data at constant speed indicates that

$$P \propto L^{2.5} W^{0.5}$$

Since the exponents sum to the total required for the length dimension in the power function and since the remaining terms (liquid depth and tank diameter) would not be expected to enter the expression to a negative power, the exponents for Z and D presumably are zero. This is confirmed by Tables 3 and 4 and by Figure 4. The correlating group thus becomes

$$\phi_a \cdot \left(\frac{L}{W}\right)^{0.5} = \frac{g_c P}{L^{2.5} W^{0.5} \mu n^2}$$

rather than the one suggested by White. It is almost identical to that developed by O'Connell and Mack (*8*) for two-blade paddles in the viscous regime in baffled tanks. This agreement confirms

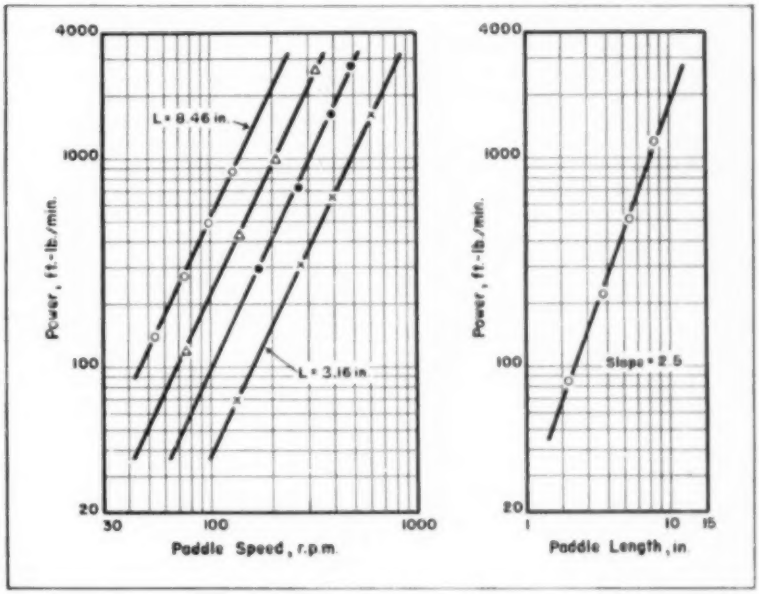

Fig. 2. Effect of paddle diameter on power.

TABLE 3.—EFFECT OF TANK DIAMETER ON AGITATOR POWER

$L = 2.86$ in., $W = 0.48$ in., $Z = 5.6$-8.2 in., $\rho = 87.9$ lb./cu.ft.

Tank Diameter, in.	Paddle Speed, rev./min.	Liquid Viscosity, cp.	Power, ft.-lb./min.	Reynolds Number	$\phi_a \cdot \left(\frac{L}{W}\right)^{0.5}$
5.6	75	89,400	64.6	0.104	65.6
	165	84,400	249	0.258	59.6
	257	81,900	526	0.424	55.0
	391	74,400	1148	0.780	62.1
8.2	52	84,400	25.4	0.080	61.1
	173	84,400	275	0.269	59.7
	307	84,400	772	0.480	53.2
11.4	96	91,800	100	0.130	59.5

Note: The power data of this table are all low by a constant amount because of bearing friction. They therefore do not correlate well with the rest of the data of this study. They are valid, however, to demonstrate the negligible effect of tank diameter on agitator power.

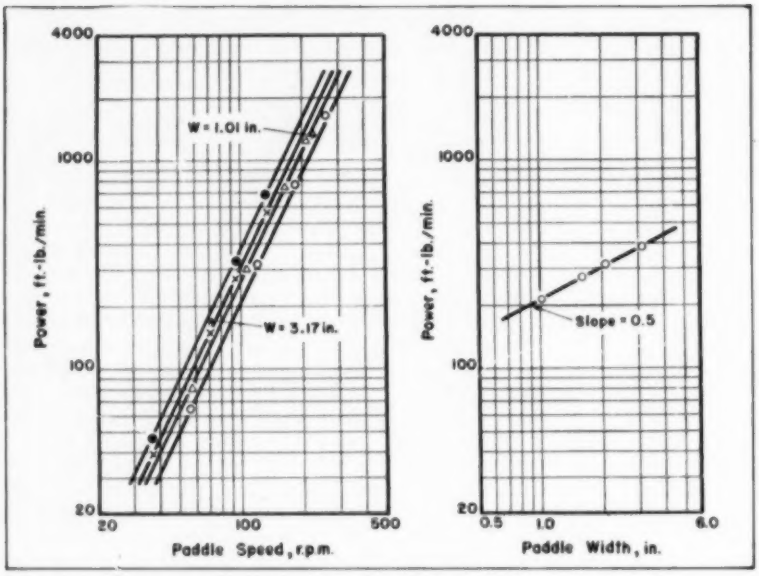

Fig. 3. Effect of paddle width on power.

for all flat-paddle designs operating in the viscous region the negligible effect of baffles previously observed by Hixson and Baum (*4*) and by Rushton (*10*) for a few specific impellers.

The effect of clearance (distance between impeller and tank bottom) on the power requirement of a flat paddle in turbulent agitation is negligibly small. This investigation indicated, however, that in high-viscosity liquids power may be affected appreciably by clearances less than 1 in. This effect is apparently viscometric and is a function more of absolute than of relative clearance. Since plant agitators seldom operate with clearance as small as 1 in., the effect was eliminated from consideration either by maintaining a clearance greater than 1 in., or by correcting the data taken at lower clearance by an experimentally determined amount.

Table 5 completes the power data, including those taken during the suspension study, and Figure 5 graphically summarizes the data. The line drawn represents all plotted points except solid circles to ±25%, and all but a few to ±15%. The solid circles represent data for extremely long paddles for which the tip-to-wall clearance was less than 1 in. The correlation is believed to fail for these values because of the viscometric drag identified with the small radial clearance, an effect similar to that for small bottom clearance. The curve should be valid for long paddles ($D/L = 1.1$) in plant equipment, however, for which the absolute radial clearance usually will be larger than 1 in.

Figure 5 shows also lines representing the data of O'Connell and Mack (*8*) for a variety of two-blade paddles in baffled tanks, and the data of Rushton, Costich, and Everett (*10*) for a paddle of specific proportions in an unbaffled tank. The agreement among the three is good.

The line of Figure 5 has been extrapolated through a critical region to join an unpublished re-evaluated line for the turbulent region. The ordinate of this graph should not be used, however, for $N_{Re} > 100$. Below this value it is believed reliable for all two-blade flat paddles in any size of unbaffled equipment. As previously discussed, agreement with the O'Connell-Mack data indicates that it may be used also for baffled tanks, or that the O'Connell-Mack correlation may be used for unbaffled ones.

Agitation of Suspensions

It has been pointed out by Stanclift (*11*) that the suspension of particulate solids in a liquid less dense than themselves involves the two distinct problems of the initial suspension and of the uniform distribution of the already suspended solids. Although the relatively low-settling velocities characteristic of most liquid-solid suspensions, whose agitation will be viscous, increase the ease of maintaining a uniform suspension once it is formed, the damping tendency of the high-viscosity liquid makes establishment of uniformity difficult and both aspects of the suspension problem are important, therefore, in viscous mixing. This statement is supported by the observations made during the test of any of the impellers examined.

Figure 6 shows the stages of progress in a typical viscous agitation as the agitator speed is increased incrementally. Each panel of Figure 6 represents a steady-state condition. In Panel 6*A* the agitator is motionless and the solids are all at rest on the tank bottom. As the agitator is rotated slowly, a sand

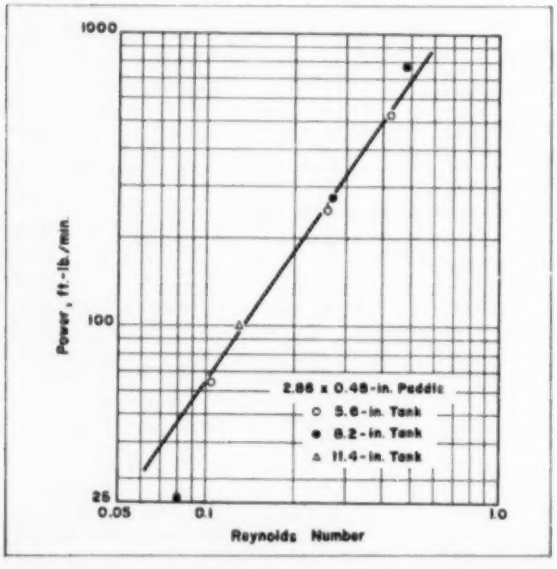

Fig. 4. Effect of tank diameter on paddle power.

TABLE 4.—EFFECT OF LIQUID DEPTH ON AGITATOR POWER

2.86-in. × 0.48-in. flat paddle in 8.2-in. tank containing 220-cp. syrup

Liquid Depth, in.	Paddle Speed, rev./min.	Dynamometer Load, g.	Power, ft.-lb./min.	Reynolds Number
4.4	126	22	12.9	2.71
6.0	126	22	12.9	2.71
8.2	126	22	12.9	2.71
11.7	126	22	12.9	2.71

TABLE 5.*—SUMMARY AGITATION POWER DATA, VISCOUS REGION

Paddle Diameter, in.	Paddle Width, in.	Tank Diameter, in.	Liquid Depth, in.	Paddle Speed, rev./min.	Liquid Density, lb./cu.ft.	Liquid Viscosity, Centipoise	Paddle Power, ft.-lb./min.	Reynolds Number	$\theta_m \cdot \left(\frac{L}{W}\right)^{0.5}$
6.19	1.03	8.2	8.2	52	86.1	6950	40.8	4.25	104
				75		7100	87.0	6.00	107
				93		6950	133	7.59	106
				112		6950	188	9.14	102
6.19	1.03	8.2	8.2	52	86.1	7220	42.7	4.08	104
				77		7150	93.6	6.11	106
				99		6950	151	8.09	106
				118		6950	216	9.63	107
6.19	1.03	8.2	8.3	39	86.5	5570	18.7	3.96	105
				52		5570	33.4	5.29	106
				60		5510	45.4	6.17	109
				69		5460	59.5	7.15	109
				79		5300	77.4	8.45	112
				88		5250	95.5	9.50	112
				101		5200	126	11.0	114
6.19	1.03	8.2	5.9	45	85.5	4950	23.6	5.13	102
				54		4850	33.0	6.27	102
				63		4810	45.4	7.38	104
				71		4770	57.4	8.39	104
				82		4690	75.1	9.86	104
				63		4690	41.4	7.57	96.9
				69		4640	49.4	8.40	97.6
				50		4720	26.5	5.96	107
				60		4690	38.1	7.21	108
				75		4640	61.2	9.11	112
				84		4600	76.0	10.3	111
				90		4600	86.1	11.0	110
				94		4570	94.4	11.6	111
2.86	0.44	11.4	11.4	110	84.3	5150	10.8	2.52	93.0
				132		5150	16.0	3.04	96.5
				403		5150	161	9.25	105
				278		5150	74.8	6.37	101
				618		5150	422	14.2	117
2.86	0.44	8.2	8.4	531	87.0	17,300	854	3.75	95.2
				490		17,300	576	3.10	93.5
				315		17,300	292	2.22	92.8
				114		17,300	39.2	0.80	94.7
				532		17,300	875	3.76	97.4
				346		17,300	354	2.44	92.8
				176		17,300	89.8	1.24	91.2
2.86	0.44	8.2	8.4	108	87.0	27,100	55.1	0.486	95.0
				35.5		27,100	5.8	0.160	92.0
				35.5		58,300	11.7	0.073	86.5
				55		58,300	27.4	0.115	84.3
				71		58,300	44.6	0.148	82.5
				108		58,300	103	0.226	82.2
				35.5		58,300	11.4	0.073	84.2

* Balance of data for this table is on file with A.D.I.

mound is first formed directly beneath the shaft, the particles flowing out towards the tip of the paddle and then returning beneath the shaft. This gives the appearance of a torus under the paddle (Panel 6*B*). With an increase in paddle speed, some of the solids leave the torus and rise along the wall of the vessel to a level which is determined by the flow conditions and by the settling velocity of the solids (Panel 6*C*). These particles then move in towards the shaft and down the shaft to the paddle. More particles follow the same path until a steady-state condition is reached where the number of particles following this route above the paddle is constant. A further increase in speed brings about the condition shown in Panel 6*D*. The sand mound still exists, but many more particles have been suspended. The suspended solids circulate about a ring-like zone of liquid (called the void ring) containing no solids. The void ring appeared during the course of every suspension observed. Increasing the speed reduces the volume of the void ring and brings about a heavier and more uniform suspension (Panel 6*E*). Complete uniformity of the suspension (except for the topmost few centimeters of liquid) is finally achieved by a further increase of agitator speed (Panel 6*F*).

The behavior described above was typical of all effective paddles, regardless of their proportions; for those too short to be effective it was typical also up to the point at which further increase of agitator speed produced no further benefit. The suspensions formed with relatively long paddles ($D/L \leqq 1.33$), however, exhibited one characteristic during their formation which was not observed for shorter paddles. At a speed less than that at which all the solids were first in suspension the suspension level (i.e., the highest level of solids in the liquid) would drop as much as 10% of its total height. Increasing the speed further would raise the level to its former height. Although the reason for this behavior is not known definitely, it may be the result of a blanketing action of the thick suspension of solids in the lower part of the vessel during one stage of the agitation.

The time required to achieve complete suspension after the final increase in speed was in most cases from 10 to 20 min., regardless of tank size. It is believed that the transient state would be little longer even if the agitator started at this speed with all the solids settled.

A complete data record can be found in the dissertation from which this paper is derived (*3*). A typical data sheet is shown as Table 6. The quantities $(N_{Re})_m$, $(P')_m$, and $(S_p)_m$ are the Reynolds number (dimensionless), power per unit volume of suspension (hp./1,000 gal.), and paddle peripheral

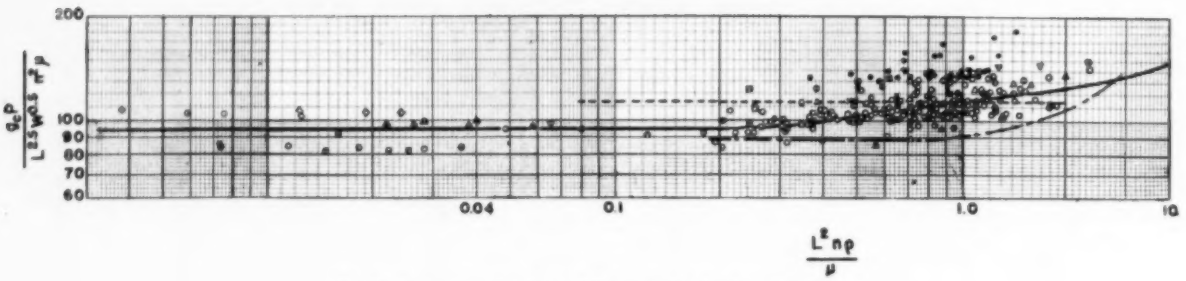

Fig. 5. Power curve for flat paddles operating in viscous regime.

▽ W = 0.12L □ W = 0.32L ● Long Paddle
○ W = 0.16L × W = 0.50L —·— Data of Rushton et al. (10).
△ W = 0.24L ◇ W = 1.0L ------ Data of O'Connell and Mack, Baffled Tanks (8).

speed (ft./min.), respectively, at the minimum agitator speed for complete suspension. These quantities were computed as potential criteria for the scale-up of effective models. They are summarized in Table 7. For equal D/L in tanks of different diameters, the data represent the behavior of a set of geometrically similar models. The reproducibility of the observations is indicated by the following pairs of runs: 24, 33; 25, 34; 14, 16; and 27, 28. In terms of power per unit volume, the maximum deviation between duplicate runs was 17%.

Table 7 shows that complete suspension occurred at about the same power input per unit volume of slurry for each of a series of geometrically similar models covering a threefold range of scale factor, in spite of the fact that the viscosity was increased with increasing scale size. Reynolds numbers, on the other hand, although deliberately maintained within the same order of magnitude, differed considerably and unsystematically in vessels of different size. These observations lead to several interesting implications:

a. An agitation system, whose function is to suspend insoluble solids in a liquid so viscous that the action will be in the laminar region, can be modeled in a geometrically similar counterpart containing a liquid of quite different viscosity, provided that the settling velocity of the solids and the agitation power per unit volume of suspension are kept the same, the action remains viscous, and the Reynolds number is of the same order.

b. Since the maintenance of equal power per unit volume in the viscous region in a series of geometrically similar models requires constant angular speed of the impellers (and hence peripheral speed proportional to the scale factor) if the liquid viscosity is the same in all models (1), and since the minimum satisfactory speed observed during this study decreased as scale size and viscosity increased, it is probable that the solids-suspending action of an agitator impeller operating in the viscous range may be scaled up safely by maintaining equal power per unit volume in geometrically similar counterparts containing the same agitated material.

c. Should it be necessary to increase the viscosity of a high-viscosity agitated suspension, the impeller will continue to be an effective suspender, although the power that it draws and presumably the shear intensity at its envelope will increase.

d. In a series of geometrically similar viscous-region systems, involving suspensions of different viscosity but the same settling velocity, the lowest agitator speed which will maintain the suspension is independent of the scale size and inversely proportional to the square root of the liquid viscosity.

e. The power per unit volume required by a paddle to maintain a suspension of solids in a high-viscosity liquid is primarily a function of the settling velocity of the solids in the liquid.

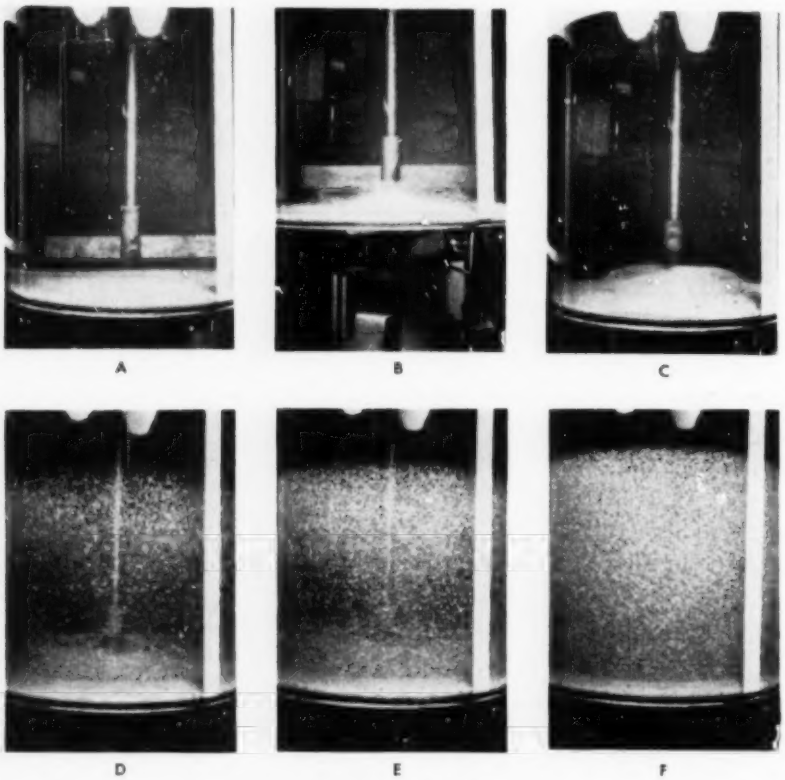

Fig. 6. Suspension formation.

It is emphasized that these generalizations are implied rather than proved and that they must be accepted with caution until further investigation establishes them as firm conclusions.

Table 7 also demonstrates the importance of paddle diameter with respect to tank diameter. As the length of the paddle was decreased (D/L increased), the power required for complete suspension increased, and the increase was sharp for values of D/L greater than 1.7. At $D/L = 2$ the power required for complete suspension was 1.5 to 3

TABLE 6.—TYPICAL DATA SHEET FOR SUSPENSION TEST

Run No. 24

$D = 8.2$ in. $\quad S = 0.83$ in. $\quad \nu = 2.74 \times 10^{-5}$ ft./sec.
$L = 6.19$ in. $\quad D_p = 0.028$ in. $\quad C_s = 2.0\%$
$W = 1.03$ in. $\quad \rho_l = 86.5$ lb./cu.ft. $\quad$ torque arm $= 3.95$ in.
$Z = 8.3$ in. $\quad \rho_s = 165.5$ lb./cu.ft.

Obs. No.	w, g.	t, °C.	μ, cp.	h, in.	N_{Re}	P, ft.-lb./min.	P', hp./1,000 gal.	S_{ss}, ft./min.	n, rev./min.
1	105	29.5	5570	....	3.96	18.68	0.294	63.1	39
2	141	29.5	5570	6.1	5.29	33.40	0.527	84.2	52
3	166	29.6	5510	6.4	6.17	45.4	0.716	97.2	60
4	189	29.7	5460	6.3	7.15	59.5	0.936	111.9	69
5	215	30.0	5300	5.6	8.45	77.4	1.220	128.0	79
6	238	30.1	5250	6.1	9.50	95.5	1.508	142.4	88
7	273	30.2	5200	6.35	11.00	125.9	1.983	163.6	101

1. Sand moving slowly across bottom, none picked up—10 min.
2. About 1% picked up forming an extremely light suspension—15 min.
3. About 3% picked up, still forming light suspension. A sand ring formed under paddle—15 min.
4. About 5% picked up above paddle, 30% forming a heavy suspension ring under paddle—15 min.
5. About 99% picked up; non-uniform suspension formed, heavy on top with "void" ring in center—20 min.
6. Uniform suspension, all picked up—10 min.
7. Reading after 10 min.

times that required at $D/L = 1.3$. At $D/L = 4$, such high speeds would have been required to suspend the solids that the Reynolds numbers would exceed the maximum allowable for the viscous range. Accordingly, no values are reported for this ratio. In one run, however, it was observed that incomplete suspension was obtained when the power input was 15 hp./1,000 gal. Paddles for which $1.7 \geq D/L \geq 1.1$ appeared to be equally effective, producing complete suspension with the application of 2 hp./1,000 gal., or less. On the other hand, increasing D/L appears to increase the maximum height (h) to which solids are carried in the liquid. For this reason, the shorter paddles in this range of effective sizes are recommended.

It is notable that the height of solids in the suspension was usually 0.6 to 0.8 times the liquid depth when complete suspension was first achieved. One run was made, therefore, in which Z/D was 0.7. A completely uniform suspension was not achieved; the sand level remained below the liquid surface when a Reynolds number of 10 was reached. The supernatant solids-free layer is not the result, therefore, of some absolute maximum height to which a given agitator can project the solids, but is rather a function of the geometry of the system as a whole and the properties of the liquid. Its existence explains the difficulty often encountered in submerging floating solids in a high-viscosity liquid. It probably can be reduced or eliminated by placement of an impeller close to the liquid surface. This should be the subject of a later detailed investigation.

Summary

1. The power consumed by a flat paddle of any proportion operating at $N_{Re} \leq 10$ in an unbaffled tank may be computed from the correlation established of $Pg_c/(L^{2.5}W^{0.5}\mu n^2)$ vs. $L^2 n\rho/\mu$ (Fig. 5). The correlation is consistent with the data of Rushton and co-workers (*10*) and agrees closely with the plot for baffled paddles presented by O'Connell and Mack (*8*). Thus, as has been previously observed for certain specific impellers (*4, 10*), the power requirement of flat paddles, irrespective of proportions, in viscous agitation is practically uninfluenced by wall baffles in the tank. The viscous section ($N_{Re} < 40$) of the correlation of White and Sumerford (*9, 11*) is in error and should not be used.

2. Agitation in the viscous region by flat paddles of a variety of proportions is marked not only by a distinctive relationship between geometry, liquid properties, and power, but also by (a) characteristic flow patterns and their effect of solid-liquid suspensions, and (b) the relatively long time required to achieve steady state in an agitated suspension.

3. It has been observed in the laboratory that flat paddles for which $W/L = 0.17$ are effective for the viscous agitation of suspensions of solids of low-

TABLE 7.—CONDITIONS FOR MINIMUM SPEED AT WHICH ALL SOLIDS ARE IN SUSPENSION

Vessel Diam., in.	Run No.	D/L	N_{Re}	P' hp./1,000 gal.	S_{ss} ft./min.	h/Z	$\nu \times 10^5$, ft./sec.
5.6	17	4.00					3.53
	18*	2.00	7.79	4.03	213	0.74	3.23
	19*	1.33	6.32	2.08	122	0.66	3.19
	20	1.33	6.22	1.50	110	0.66	3.39
	21	1.11	6.14	1.33	83	0.61	3.64
8.2	7	4.00					1.82
	22	.400					2.67
	23	2.00	12.4	2.31	226	0.81	2.85
	35	1.66	9.88	1.48	170	0.75	3.09
	9*	1.33	9.14	2.96	182	0.79	2.35
	10*	1.33	9.63	3.40	191	0.82	2.24
	24	1.33	9.50	1.51	142	0.74	2.74
	33	1.33	11.6	1.50	152	.075	3.21
	11*	1.11	10.0	2.70	146	0.77	2.63
	25	1.11	10.2	1.61	122	0.72	2.83
	34	1.11	10.5	1.52	122	0.72	3.06
11.4	12	4.00					3.25
	13	2.00	16.5	6.10	399	0.89	3.33
	14	1.33	9.81	1.80	169	0.79	3.36
	16	1.33	9.75	1.56	160	0.77	3.60
	15	1.11	8.70	1.54	124	0.76	3.29
17.6**	31	4.00					3.09
	30	2.00	11.8	5.75	419	0.88	2.96
	27	1.33	10.61	1.97	202	0.77	3.68
	28	1.33	9.56	1.69	188	0.76	3.61
	26	1.11	8.86	1.82	152	0.69	3.55

* Values are in doubt because speed was advanced too rapidly for precise observation of minimum speed at which complete suspension occurred.

** Tank bottom and a fillet of shorter radius than the others; solids collected in this fillet were difficult to suspend and may account for the higher power values.

settling velocity in liquids for which $Z/D \leq 1$, provided the ratio of agitator diameter to tank diameter is not less than 0.6. Effective suspension of low-settling velocity solids (10^{-4} to 10^{-3} ft./sec.) was achieved with such paddles at power applications of 1.5 to 2 hp./1,000 gal.

4. Small-scale models of flat-paddle agitators that effectively agitated solid-liquid suspensions in the viscous region were successfully scaled up over a threefold range of linear dimension by the maintenance of geometrical similarity and by the application of equal power per unit volume of slurry, even though the liquid viscosity varied several fold over the span of scale sizes (Reynolds numbers were all within the same order of magnitude).

5. Observations of degree of suspension made in this study were visual and semiquantitative and were limited to tanks no larger than 1.5 ft. in diam. Conclusions based on them should be applied in larger plant equipment with caution until confirmation for equipment of such size is available.

Acknowledgment

The authors wish to acknowledge the donation of the sand and the nepheline syenite used in this study; the former was contributed by the Ottawa Silica Co., Ottawa, Ill., and the latter by the Great Lakes Foundry Sand Co., Detroit, Mich. They also wish to thank D. L. Stonger for assistance in data collection and Fred Kurata for photographic assistance.

Notation

a, b, c = exponents for shape factors in agitation power correlation
B = clearance between paddle and tank bottom, ft.†
C_s = concentration of solids in suspension, wt. %
D = tank diameter, ft.†
D_p = particle diameter, in.
g_c = gravitational conversion factor, 115,700 (ft.)(lb. mass)/(min.)(min.)(lb. force)
h = height above tank bottom to which solids are suspended, ft.†
L = paddle diameter or tip-to-tip length, ft.†
n = angular speed of paddle, rev./min.
N_{Re} = agitation Reynolds number, $L^2 n\rho/\mu$
P = power delivered by agitator blade, ft.-lb./min.
P' = agitation power/unit volume of agitated liquid, hp./1,000 gal.
S_p = peripheral speed of paddle, ft./min.
v = settling velocity of solid particle in liquid, ft./sec.
w = dynamometer load at balance, g.
W = agitator blade width, ft.†
Z = depth of agitated liquid, ft.†
μ = absolute viscosity of agitated liquid, lb./(ft.)(min.)‡
ρ = density of agitated liquid, lb./cu.ft.
ρ_s = true density of solid particles, lb./cu. ft.
ϕ_μ = power function involving viscosity, $g_c P/(L^3 \mu n^2)$
ϕ_ρ = power function involving density, $g_c P/(L^5 \rho n^3)$

† Except when inches are indicated as the unit.

‡ Except when centipoises are indicated as the unit.

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Discussion

C. R. Bartels (E. R. Squibb & Sons, New Brunswick, N. J.): On the basis of the work you have done, have you any opinion on suitable means for incorporating the clear liquid layer which appears above the suspension?

S. A. Miller: The work that we did was entirely limited to a single impeller placed relatively close to the bottom of the tank. Some firms that have had experience in the handling of materials of high viscosity have long said that one should have a multiple impeller, that is, at least two units up and down the shaft, one of which should be near the surface. We know that as an impeller is brought closer to the liquid surface, that surface begins to move, whereas it had been stationary. Therefore, we believe there is every reason to accept the statement that a second impeller near the surface would at least assist the problem of suspending materials, which is no mean problem if they tend to float on the high viscosity surface, and possibly would also help uniformize the suspension. We hope to find out, but we haven't done so yet.

Frank H. Conrad (University of Missouri, Rolla, Mo.): Did you investigate the effect of baffles in the tank? As I recall it, Professor Rushton found that baffles were quite effective in increasing the efficiency of that kind of mixing required to obtain uniformity.

S. A. Miller: We did not. What you say is true as long as one stays in the turbulent region. If he gets to a Reynolds number of less than 10, however, at best the baffle does nothing, and at worst it does harm.

In the first place, I should point out that these power data are valid whether the tank is baffled or not. Rushton has shown that with turbines and propellers the curves draw together at the critical point. The same curve applies to the baffled or unbaffled conditions. This is reasonable because the agitator really doesn't know what is very far beyond itself. It doesn't know whether it is a square tank or a round tank with baffles or not, because it operates in a relatively highly localized envelope.

The reason I say that in the worst case it can do some harm, is that sometimes, at the edge of the viscous region, there is a little surface motion; this motion is completely stopped by baffles, with the result that solids can be trapped behind a baffle. That doesn't mean, however, that baffles are always ineffective in viscous materials. The criterion is not the viscosity of the material, remember, but the Reynolds number and, therefore, in some viscous materials if the equipment is large, baffles may be helpful.

B. J. Gaffney (U. S. Industrial Chemicals Co., New York 17, N. Y.): I have always wondered about one theoretical as well as a practical point. What is the effect of the whip action at the bottom of an agitator which does not have a foot bearing. I just wonder whether you think that contributes something to the scattering of your plotted data?

S. A. Miller: No, we don't think so. In our case we had a number of shafts, one of which got deformed enough so that it whipped badly. As near as we could tell, the same paddle (the paddles in general were interchangeable with shafts) gave us the same results with deformed and undeformed shafts. Actually, in industry, one avoids shaft whip if he possibly can, even by the use of an undesirable foot bearing, because it can cause a costly shutdown. I think, however, that there was no effect on our measurements.

The Role of Porosity in Filtration

Numerical Methods for Constant Rate and Constant Pressure Filtration Based on Kozeny's Law

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Based upon the Kozeny law relating the rate of flow to the porosity, a method has been developed for determining (a) the pressure drop vs. the depth and the flow rate vs. the applied pressure in a fixed bed of solids, (b) the pressure vs. time relationship in constant rate filtration, and (c) the volume vs. time relationship in constant pressure filtration. It is assumed that the porosity is solely a function of the pressure on the solids, thus eliminating solids such as certain naturally occurring clays in which application of pressure causes only a slow approach to the equilibrium porosity.

Experimental porosity vs. pressure data are presented for such materials as kaolin, calcium carbonate, carbon black (suchar), diatomaceous earth (hyflo), asbestos, and mixtures of these materials. As a satisfactory approximation, the per cent voids can be related to the pressure by a power function with powers ranging from 0.01 to 0.05 for applied pressures up to 100 lb./sq.in.

Numerous authors (*1, 4, 6, 7, 11*) have recognized the importance of porosity in filtration. As long ago as 1937, Tour (*11*) developed equations relating the filtration resistance to the porosity variation throughout a fixed bed of solids. Experiments which he performed clearly indicated that the pressure gradient on a liquid passing through a solid was changing and that the porosity was not constant. While Tour's procedure was sound, some of his equations relating porosity to pressure were not tested, and the work was not published. Ruth (*9*), in the period 1932-37, also developed a procedure for relating the filtration variables in a solid of variable porosity. Carman (*1*) focused attention on Kozeny's equation involving the rate of flow as a function of the porosity and other variables. Several other investigators considered Kozeny's equation but have not used it in the best manner in filtration equations. In this paper the Kozeny equation is used as a basis for developing the differential equations of filtration. These equations are used in connection with fixed beds of solids, constant rate filtration of a solid with and without precoat, and constant pressure filtration with and without a precoat.

Factors Involved in Filtration

In the filtering of solids from suspensions or in any process in which a liquid flows through the interstices of a solid, the flow is in the direction of decreasing pressure. The solids are supported on a screen, cloth, or other solid bed known as the septum or filter medium. In ordinary filtration practice, the solids closest to the septum are packed more densely than the rest of the cake. The porosity is a minimum at the point of contact between the cake and the septum and is a maximum at the surface where the liquid enters. Since the filtration resistance depends upon the porosity, the resistance steadily increases as the liquid passes through the cake if the solids are compressible. In order to treat quantitatively the filtration problem, it is necessary to have relationships between the rate of flow, pressure on the liquid, and the porosity in addition to the various parameters. The information necessary to an understanding of the methods used in this paper is summarized as follows:

1. Relation of porosity to pressure on the solids. Data (*7, 8, 12*) are presented in addition to new data. It is indicated that the porosity may be empirically related to the pressure on the solids by a power function, in the pressure range up to 100 lb./sq.in.
2. Relation of pressure on solids to pressure on liquid. From the standpoint of a problem in statics, a free body analysis of the solid and liquid shows that the pressure on the solid increases as the liquid passes frictionally through the pores.
3. The Kozeny equation as presented by Carman is used as a basis for relating the rate of flow to the pressure gradient on the liquid, porosity, specific surface of the solid, and the viscosity. Other laws relating the flow rate to the pressure gradient could be used equally well.

Porosity vs. Pressure on Solids

In the field of soil mechanics, the per cent voids or void ratio is frequently determined as a function of the applied load. The apparatus employed consists essentially of a container, termed a consolidometer, in which samples can be placed and subjected to vertical loading. In the simplest type of testing, the sample is placed between porous plates and kept saturated with water while the load is applied. At the instant the load is added, the stress is applied to both the solid particles and the liquid within the interstices. Since the liquid is free to flow through and around the porous plates, the excess of liquid pressure above atmospheric, referred to as the neutral stress, causes the moisture to leave the voids (Fig. 1), resulting in a consolidation of the solids. As the water flows out, the neutral stress drops, the solids finally carrying the applied load. When the entire load is borne by the solids as indicated in Figure 2 the actual pressure on the solids is given by

$$\text{pressure on solids} = \text{applied pressure}/(1-\epsilon) \qquad (1)$$

where ϵ is the equilibrium value of the per cent voids by volume or porosity and $(1-\epsilon)$ is equal to the average true area of the solids per square foot.

Frank M. Tiller, who had received the A.I.Ch.E. Junior Member Award in 1950, was again a winner at the 1952 Cleveland meeting, where this paper earned the best presented paper award. A B.Ch.E. of the University of Louisville and a Ph.D. of the University of Cincinnati, he taught two years at Cincinnati, nine years at Vanderbilt University, and a short time at the Instituta de Oleos in Rio de Janeiro. He is now director of engineering at Lamar State College of Technology, Beaumont, Tex.

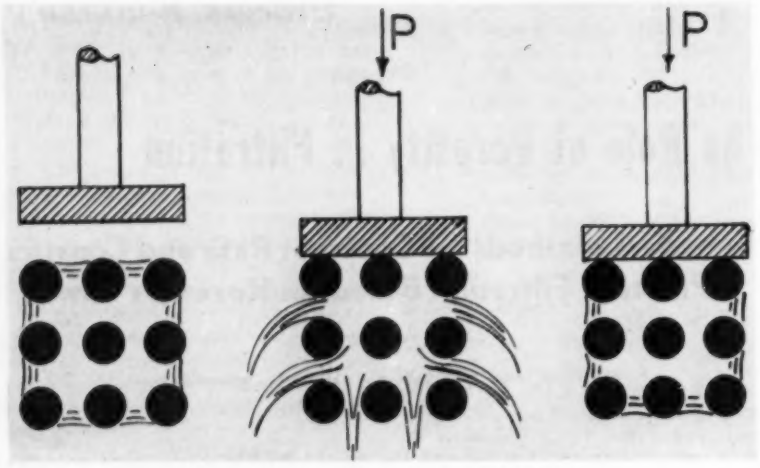


Fig. 1. Compression process in a consolidometer.

In this type of test, the liquid is not confined, and the neutral stress must approach zero. The rate of flow of the water from the sample depends upon the permeability, and the time required to reach equilibrium ranges from a few minutes for the materials used in this investigation to 24 hr. for soils classified as clays. In addition to the primary equilibrium which is reached, there is a secondary creep effect which may continue more or less indefinitely.

In another procedure known as triaxial compression testing (*10*), the sample is placed in a water-tight covering in which the liquid pressure P_x, or neutral stress, can be controlled. After adjusting the neutral stress, an independent external load is added which results in compression of the solids as indicated in Figure 3. The neutral stress acts equally in all directions and does not affect the porosity; thus the external load over and above the neutral stress $(P - P_x)$ is responsible for compression and decrease of the voids. Actually in triaxial testing, the solid is not confined laterally and changes in dimensions occur along all three axes.

In filtration, the neutral stress in the consolidometer and triaxial soil compression tests is equivalent to the liquid pressure in the interstices of the cake. In the static tests the neutral stress is constant throughout the solid; whereas, in filtration the liquid pressure decreases in the direction of the flow of the filtrate. In this investigation it is assumed that the liquid pressure does not affect the porosity. Then the results obtained in the simple consolidometer can be used for predicting relationships between porosity and pressure on the solids in a filter cake.

Ruth (*8*) developed an ingenious permeability-compression apparatus in which filtrations could be carried out while the pressure on the solids was controlled independently. Loads were added in a manner similar to that used in the consolidometer except that a perforated plate confined the solid at both top and bottom. After loading the solids, liquid was introduced separately and allowed to flow through the solids under relatively small heads. With this procedure the porosity of the solids could be controlled at an essentially constant value while the filtration was performed.

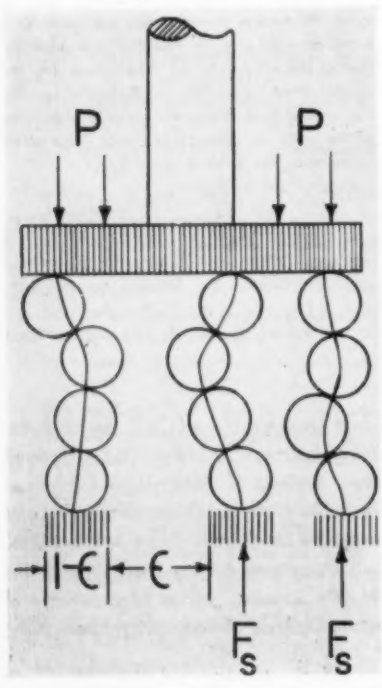


Fig. 2. Left, Equilibrium state in compression process.

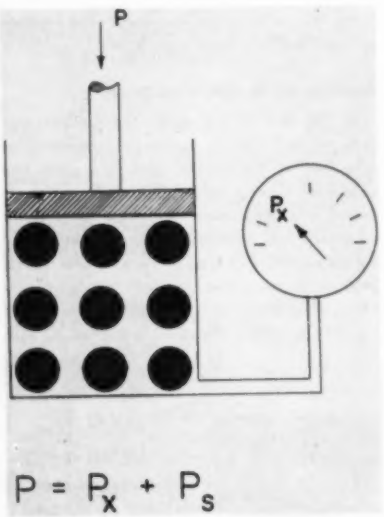


Fig. 3. Above, Distribution of load between solids and liquid.

EXPERIMENTAL DETERMINATION OF POROSITY VS. APPLIED LOAD

The porosity was determined in a consolidometer consisting of a brass cup in which a wet solid could be compressed by a suitable loading procedure. The cup was approximately 5 sq.in. in area, and the solid depth was initially about 1 in. The wet solid rested on a porous plate through which moisture could flow as it was squeezed out of the solid. In most of the runs a lever system was used so that the load on the solid was four times the weight employed. An Ames dial served for measuring the thickness of the solid. The procedure consisted of the following:

1. The total depth was found before the sample was placed in the consolidometer on top of a porous stone.
2. After the wet solid was placed in the cup, a second porous stone and brass plate were placed on top of the solid and 10 min. allowed to elapse before the first reading was recorded.
3. Weights were added and 10 min. allowed between readings.
4. After this procedure, the moisture content of the solid was determined, and porosities were calculated based upon the readings and the final porosity.

The final per cent voids were calculated from the per cent moisture z of the cake at the end of the tests in the following manner:

$$\epsilon = \frac{\text{void vol.}}{\text{void vol.} + \text{solid vol.}}$$

$$= \frac{z/62.4}{z/62.4 + (1-z)/\rho_s} \qquad (2)$$

$$\epsilon = \frac{z(\text{sp.gr.})}{z(\text{sp.gr.}) + (1-z)} \qquad (3)$$

where ρ_s is the density of the solids and

$\rho_s/62.4$ is the sp.gr. Data and sample calculations are shown in Table 1.

The procedure outlined was applied to a diatomaceous earth (hyflo), kaolin, activated carbon (suchar), calcium carbonate, mixtures of kaolin and hyflo, mixtures of suchar and hyflo, and asbestos.

The final moisture content was 25.86%. The final porosity is calculated from Equation (2) using a value of 2.60 for the specific gravity of kaolin. Thus

$$\epsilon = \frac{(2.6)(0.2586)}{(2.6)(0.2586) - 0.7414} = 0.476$$

Calculation of porosity at 11:30

Reduction in thickness = 0.4542 − 0.3192 = 0.1350 in.

Cake thickness = initial value − 0.1350 = 1.018 − 0.135 = 0.883 in.

Cake volume = (area)(thickness)(16.4 cc./cu.in.) = vol. in cc. = (4.988)(16.4)(thickness) = (81.7)(0.883) = 72.1 cc.

Total volume of solids remains constant and can be obtained from the final porosity.

Volume of solids = (1 − .476)(62.7) = 32.8 cc.

Porosity at 11:30 = (72.1 − 32.8)/72.1 = 0.545

Empirical equation as found from Figure 5

$\epsilon = 0.59 p_s^{-0.045}$

In the first stages of the investigation, the effect of both time and pressure on the porosity were determined. In Figure 4 the porosity of crushed limestone is plotted against the time at different applied pressures. It can be seen that about 5 min. were required to approach apparent equilibrium closely. With natural clays and similar materials, the time required to reach an apparent equilibrium is much longer.

In some runs thickness and porosity determinations were made as the pressure was reduced, i.e., after completing the addition of loads on the sample in the consolidometer, the loads were removed and Ames dial readings recorded. Little increase in porosity was noted, and the conclusion was reached that the compression process was essentially irreversible. Carman (1) also indicated that his data pointed to the irreversibility of the compression process with most solids.

In Figure 5 some of the porosity vs. pressure data are plotted logarithmically. As a fair approximation in the ranges investigated, Figure 5 indicates that a power function of the form

$$\epsilon = \epsilon_o p_s^{-e} \qquad (4)$$

Table 1.—Data and Sample Calculations for Consolidometer Tests

Porosity run No. 10 Area of cake 4.988 sq.in.
Substance: kaolin
Final moisture content 25.86%

TIME	AMES DIAL READING IN.	APPLIED LB./SQ.IN.	CAKE THICKNESS IN.	VOL. CC.	POROSITY
Initial	0.4542	.....	1.018	83.2	.698
10:30	0.3240	.....			
10:40	0.3089	0.28	.....	.....	
11:00	0.3790	1.42	0.943	77.0	.574
11:10	0.3490	3.04	0.913	74.6	.560
11:20	0.3283	5.18	0.892	72.8	.549
11:30	0.3192	6.87	0.883	72.1	.545
11:40	0.3097	8.58	0.873	71.3	.540
11:50	0.2942	12.92	0.857	70.0	.531
12:00	0.2762	19.94	0.839	68.5	.521
12:10	0.2639	27.00	0.827	67.5	.514
12:20	0.2557	33.99	0.819	66.9	.509
12:30	0.2394	47.93	0.803	65.6	.499
12:40	0.2279	61.88	0.791	64.8	.493
12:50	0.2191	75.82	0.782	63.8	.486
1:00	0.2118	89.72	0.775	63.3	.481
1:10	0.2050	103.57	0.768	62.7	.476

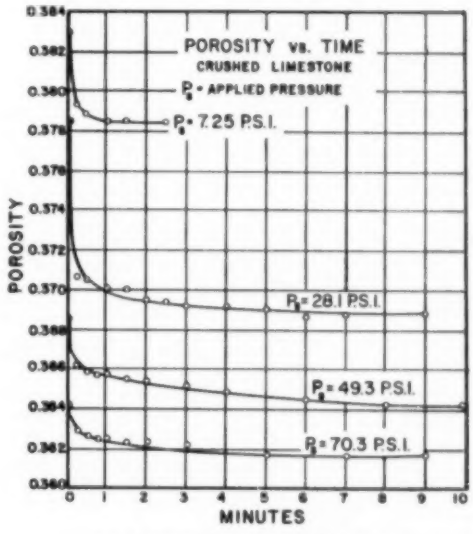


Fig. 4. Variation of porosity with time.

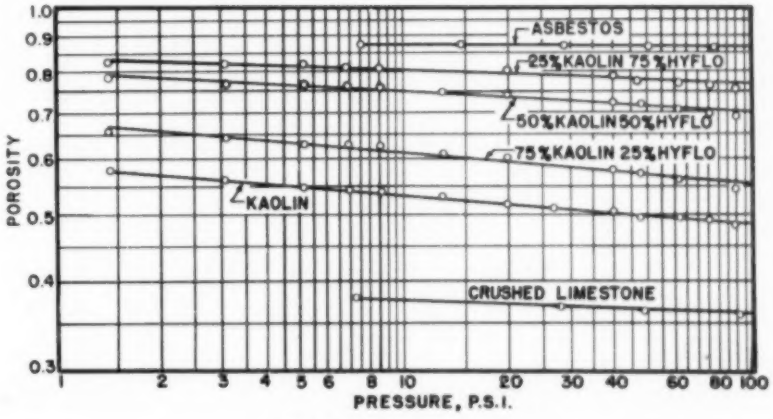


Fig. 5. Porosity vs. pressure.

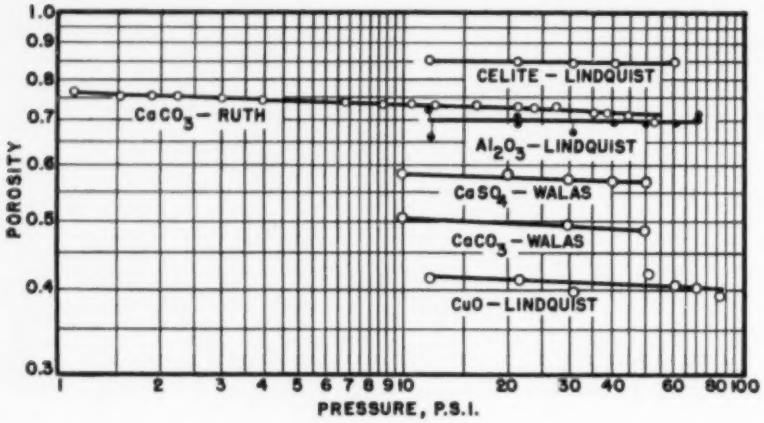


Fig. 6. Porosity vs. pressure.

Table 2

SUBSTANCE	Literature Cited	ϵ_0	c	MAXIMUM DEVIATION IN ϵ
Crushed limestone		0.39	0.015	0.005
Calcium carbonate	Ruth (8)	0.77	0.034	0.002
Calcium carbonate	Walas (12)	0.55	0.036	0.005
Calcium sulfate	Walas (12)	0.66	0.018	0.002
Ferric oxide	Walas (12)	0.81	0.037	0.02
Magnesium carbonate	Walas (12)	0.90	0.011	0.003
100% hyflo 0% kaolin		0.88	0.014	0.01
75% hyflo 25% kaolin		0.85	0.020	0.02
50% hyflo 50% kaolin		0.81	0.032	0.02
25% hyflo 75% kaolin		0.68	0.044	0.018
0% hyflo 100% kaolin		0.59	0.045	0.008
66.7% hyflo 33.3% suchar		0.88	0.013	0.008
0% hyflo 100% suchar		0.89	0.0091	0.002
Asbestos		0.91	0.017	0.008
Aluminum oxide	Lindquist and Youle (7)	0.70	0.0047	0.03
Celite	Lindquist and Youle (7)	0.86	0.013	0.03
Copper oxide	Lindquist and Youle (7)	0.42	0.021	0.04
Carbon, norit A	Lindquist and Youle (7)	0.70	0.021	0.05

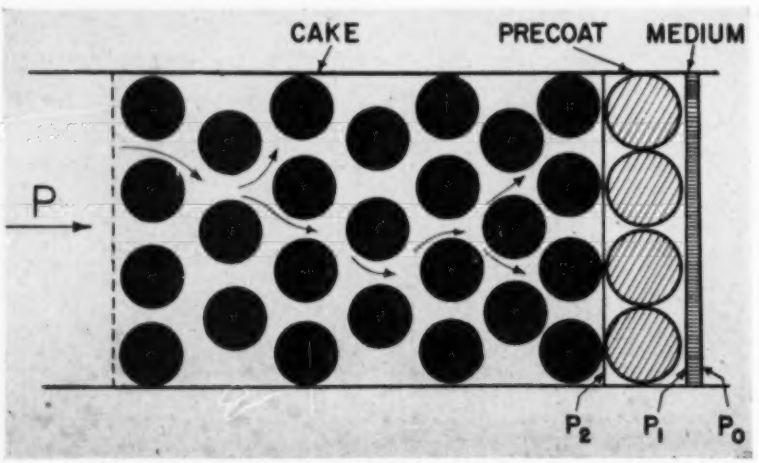


Fig. 7. Illustration of compressibility effects in a filter cake.

may be employed for representing the data where p_a is in pounds force/sq.in. In Figure 6 data of Lindquist and Youle (*7*), Ruth (*8*), and Walas (*12*) plotted in a similar manner appear to follow the same relation. Values of ϵ_0 and c, as found from the graphs, are given in Table 2.

Terzaghi and Peck (*10*) have used a semilogarithmic plot for representing a linear relation of void ratio to applied pressure in the range of 10-100 kg./sq.cm. (142-1420 lb./sq.in.) for sand. At the higher pressure, the sand grains begin to crush. For some clays the semilogarithmic relation yielded linear relations up to applied pressures as high as 1000 kg./sq.cm. In terms of the variables used in this investigation, the Terzaghi relation is given by

$$\frac{\epsilon}{1-\epsilon} = c_1 \ln P_a + c_2 \qquad (5)$$

While this expression is adequate in the high pressure range, it is not satisfactory at low pressures which are important in filtration. In this paper the analytical form of the pressure-porosity relationship is not of importance except as it may be used for interpolation. However, in the succeeding paper (Part II) where an analytical equation is developed for the filtration variables, the form of the equation is vital to the mathematical work.

Grace (*5*) has indicated that the power function approximation (*4*) for the porosity is not satisfactory above 100 lb./sq.in. in accord with Terzaghi and Peck. Therefore, at all times the use of Equation (4) should be examined with care.

Equation (4) is not satisfactory as p_a (lb./sq.in.) approaches zero (atmospheric pressure) since an infinite value of ϵ is predicted. Actually, after the pressure is dropped below about 0.1 lb./sq.in. gauge pressure, the porosity tends to approach a limiting value. As a general guide, Equation (4) should not be used below 0.1 lb./sq.in. for compressible materials. Little error will be involved if the porosities below approximately 0.1 lb./sq.in. are assumed constant.

Pressures on Liquid and Solids During Filtration

A schematic diagram of the flow of a liquid through a bed formed from a compressible material is illustrated in Figure 7. The particles are shown in a manner which indicates that the porosity is decreased as the liquid passes through the solids and approaches the septum in accord with common knowledge. In Figure 8 the liquid is shown as it passes frictionally along the particles in the filter bed. The drag on each particle

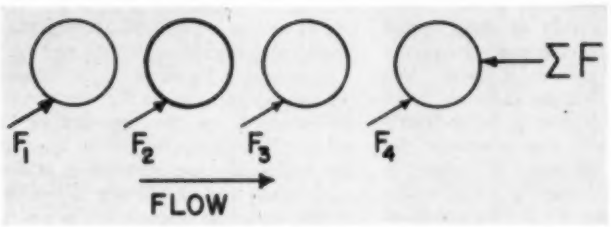


Fig. 8. Accumulative drag in a filter cake.

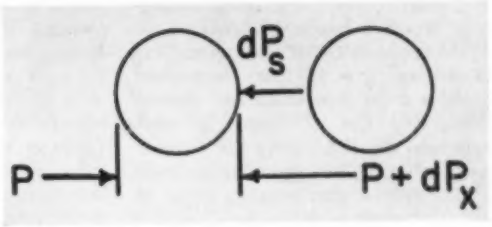


Fig. 9. Force balance around a particle.

adds to the drag on the previous particle; and consequently, the net compressive pressure builds up as the filter medium is approached, thus accounting for the decreased porosity.

At the entrance to the cake, both the pressure on the liquid P_l and the pressure on the solids are equal to the applied pressure P.† However, the applied pressure does not represent the net compressive pressure on the solids. Grace (5) and Ruth (9) have assumed that there is point contact between the particles as indicated in Figure 9 which illustrates the conditions at the surface. The pressure P at the surface of the solids is counterbalanced by a pressure $P + dP_x$ and the net increase in compressive pressure on the first layer of solids is $(-dP_x)$. Thus, as the differential pressure drop is negligible for the surface layer of the cake, the net compressive pressure P_s at the surface is essentially zero regardless of the applied pressure. The build-up of compressive pressure throughout the cake will be in accord with the relation

$$dP_s = -dP_x \tag{6}$$

which is equivalent to

$$P_s + P_x = P \tag{7}$$

Equation (6) is predicated on the basis of point contact and would have to be modified if there were area contact between particles. Equation (7) is equivalent to writing a force balance stating

force at surface = force on solids + force on liquid

It should be noted that pressures of Equation (7) are computed on the basis of the total cross section and not upon the area of the voids or solids.

When the liquid enters the cake $P = P_g$, and from (7) it can be seen that $P_s = 0$. As P_g decreases, P_s increases; and if the liquid leaves at atmospheric or zero gauge pressure, P_s will increase to P.

† Capital letters P, P_x, and P_s will be used for pressures expressed in lb./sq.ft., and small letters p, p_x, and p_s will be used when lb./sq.in. is employed.

The pressure on the solids can be eliminated from (7) to give a direct relationship between the liquid pressure and the porosity. The elimination of P_s can be accomplished either with the experimental porosity vs. pressure data or by means of Equation (4). If Equation (4) is used, there results (in terms of lb./sq.in.)

$$p_x = p - p_s = p - \left| \frac{\epsilon_0}{\epsilon} \right|^{1/c} \tag{8}$$

or solving for ϵ

$$\epsilon = \epsilon_0 (p - p_x)^{-c} \tag{9}$$

The slope of the ϵ vs. p_x curve is given by

$$\frac{d\epsilon}{dp_x} = -c\epsilon_0 (p - p_x)^{-c-1}$$

$$= -\frac{c}{\epsilon_0^{1/c}} \epsilon^{\frac{c+1}{c}} \tag{10}$$

The variation of ϵ with p_x throughout a cake for various filtration pressures for the kaolin of Table 1 is illustrated in Figure 10. Equation (10) indicates that the slope of the curves depends only on the porosity and not p_x, and this is borne out by the curves in Figure 10. Even at the lowest pressure, the porosity

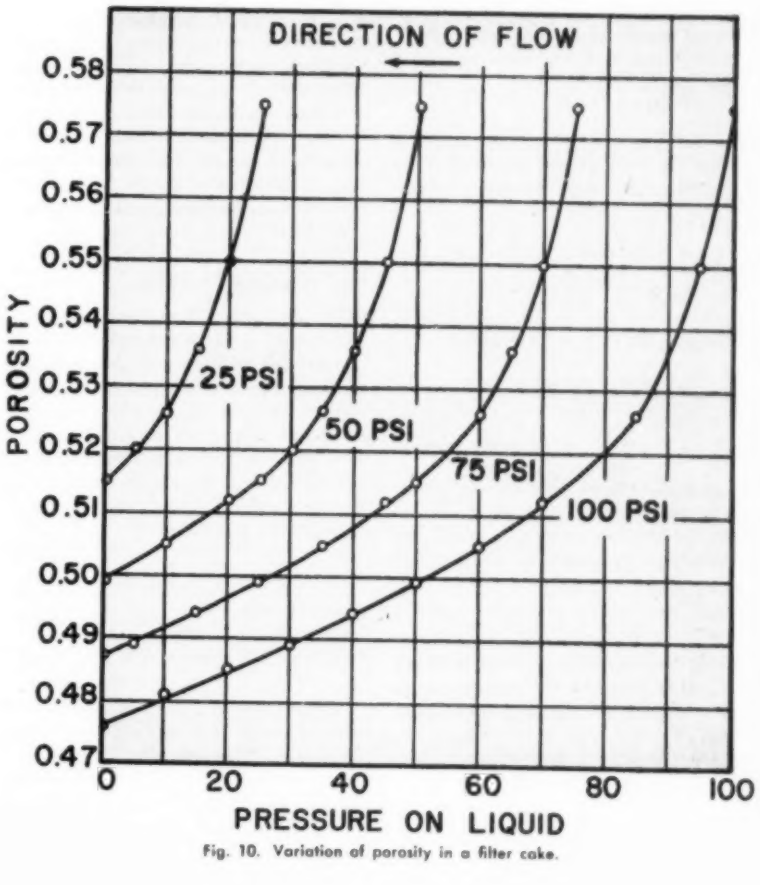


Fig. 10. Variation of porosity in a filter cake.

varies from 51.5 to 57.5%, which according to Kozeny's law would give a two-fold change in filtration resistance. Several authors (*1, 6, 12*) have determined porosities under flow conditions without investigating the variations in voids throughout the bed. Since the porosity does vary, sampling procedures should be such that a true average value of moisture content is determined. At low pressures the porosity may change quite rapidly with materials like asbestos and kaolin, and low heads are no guarantee of a negligible variation in porosity.

Kozeny Equation

The Kozeny equation (*3*) relating rate of flow through a bed of solids can be derived from the following modified form of the Poiseuille equation.

$$g_c \frac{dP_x}{dx} = -\frac{k\mu}{R_H^2} u \qquad (11)$$

where k is a dimensionless constant, u the lineal velocity in ft./sec., μ the viscosity in lb.m./(ft.)(sec.); R_H the hydraulic radius, P_x the pressure in lb.f./sq.ft., $g_c P_x$ is the pressure in lbl./sq.ft., and x is the distance. The hydraulic radius is given by

$$R_H = \left(\frac{\text{flow area}}{\text{wetted perimeter}}\right)\left(\frac{\text{length of path}}{\text{length of path}}\right) = \frac{\text{void volume}}{\text{surface of solids}} \qquad (12)$$

Since the value $\epsilon/(1-\epsilon)$ represents the ratio of the void volume to the volume of the solids, the void volume is given by

$$\text{void volume} = \frac{\epsilon}{1-\epsilon}(\text{volume of solids}) \qquad (13)$$

Substituting (13) in (12) yields

$$R_H = \frac{\epsilon(\text{volume of solids})}{(1-\epsilon)(\text{surface area of solids})} \qquad (14)$$

The surface area of the solids per cubic foot of solids (exclusive of voids) is termed the specific surface, S_o which can be substituted in Equation (14) to yield

$$R_H = \frac{\epsilon}{1-\epsilon}\frac{1}{S_o} \qquad (15)$$

The true velocity u in the interstices of the solids is given by the superficial velocity q cu.ft./(sec.)(sq.ft.) or ft./sec. divided by the per cent voids, i.e., $u = q/\epsilon$. Making substitutions in the modified Poiseuille equation leads to

$$\frac{dP_x}{dx} = -\frac{k}{g_c}\mu\frac{(1-\epsilon)^2 S_o^2}{\epsilon^3} q \qquad (16)$$

If consistent units, i.e., pound mass, poundal, foot, second; or slug, pound force, foot, second, are used, k has the value of $5g_c$. However, if inconsistent units are used with the pressure being pounds force/sq.ft. and μ being lb.m./(ft.)(sec.), k has approximately the value of 5.0. In this paper, P_x is used in lb.f./sq.ft. and k is taken as 5.0. Carman investigated Equation (16) for values of S_o ranging from 1,800 to 600,000 sq.ft./cu.ft. of solid.

For round or square particles and for cylindrical particles with length equal to diameter, S_o has the value of $6/D$. For cylindrical particles with length twice the diameter, $S_o = 5/D$. For irregular particles, Dallavalle (*2*) reports that in general the surface area is given by a constant divided by an average diameter. For rounded particles the constant was 6.1; for subrounded particles, 6.4; for sharp particles, 7.0; and for angular particles, 7.7.

Ruth (*6, 7*) has indicated that the Kozeny equation should be modified by replacing ϵ by $(\epsilon - \epsilon_e)$ where ϵ_e is a constant representing a portion of the voids unavailable for flow, termed the dead volume. Grace (*5*) has indicated that Ruth's dead volume hypothesis is not valid and that in general Kozeny's equation is inadequate. Grace also has shown that the value of k in Equation (16) is not constant and has investigated its variation with porosity. No attempt has been made in this paper to evaluate either the validity of Ruth's modification or Grace's experimental data, and calculations have been made directly with the unmodified Kozeny equation. The methods fundamentally would be the same regardless of the functional nature of the right-hand side of Equation (16).

Flow Through a Fixed Bed

The fundamental problem involved in the flow of a liquid through a fixed bed of solids revolves about the calculation of the pressure as a function of the distance. The use of Equations (7) and (16) in conjunction with either Equation (4) or actual porosity vs. solid pressure data permits the calculation of P_x vs. x. Variables involved may be summarized as follows:

EQUATION DESCRIPTION	VARIABLES	CONSTANTS	EQ. NOS.
Kozeny flow rate	P_x, ϵ, x	q, k, μ, S_o	(16)
Solid and liquid pressures	P_x, P_s	P	(7)
Porosity vs. solid pressure	ϵ, P_s	ϵ_e, c	(4)

There are four variables P_x, P_s, ϵ, and x from which it is desired to eliminate P_s and ϵ. Theoretically, P_s should be eliminated between (4) and (7) to give a relation between ϵ and P_x similar to (9). The porosity should then be eliminated between (9) and (16) to give a differential equation in P_x and x. Methods of this paper will be devoted to the graphical integrations of the equations.

In assuming Equation (4) to be valid, the assumption is made that the porosity depends only on the pressure on the solids. This is equivalent to assuming that the equilibrium porosity is attained immediately and is contrary to the facts as illustrated in Figure 4. When the pressure is built up slowly as in industrial constant rate filtrations, it is probable that the time effect on consolidation is unimportant. However, if the rate is quite high as exemplified by many laboratory investigations, the time effect probably cannot be neglected. In constant pressure filtration, the initial deposition of solids at a high rate may represent a case in which the time effect is important. Both the nature of the solids and the total filtration time will determine the importance of the transitory period in which the porosity is a function of time as well as pressure.

Suppose a liquid flows into a rectangular bed of fixed thickness (Fig. 7) under an applied pressure P, while at the opposite side the liquid leaves at pressure P_1 which is necessary to overcome the resistance of the septum. At the point where $x = 0$, the liquid pressure is P; and at the other side where $x = L$, the value of P_x is P_1.

The Kozeny equation may be rearranged for integration to give

$$\frac{kq\mu S_o^2}{g_c}\int_o^L dx = -\int_P^{P_1}\frac{\epsilon^3}{(1-\epsilon)^2} dP_x \qquad (17)$$

Reversing the limits on the right-hand side to eliminate the negative sign and integrating the left-hand side yields

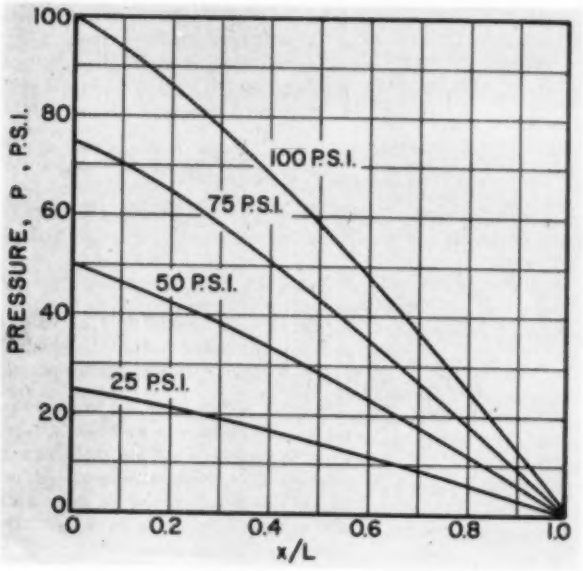
$$\frac{kq\mu S_o^2 L}{g_c} = \int_{P_1}^{P}\frac{\epsilon^3}{(1-\epsilon)^2} dP_x \qquad (18)$$

where the right-hand side must be evaluated numerically. The value P_1 represents the pressure at which the liquid leaves the solid at $x = L$, and corresponds to the pressure required to overcome the resistance of the septum. If the upper limits in (17) are x and P_x corresponding to some arbitrary point in the bed of solids, integration produces

$$\frac{kq\mu S_o^2 x}{g_c} = \int_{P_x}^{P}\frac{\epsilon^3}{(1-\epsilon)^2} dP_x \qquad (19)$$

Table 3

p_s (pound per square inch)	0	10	20	30	40	50	60	70	80	90	100
p_z (pound per square inch)	100	90	80	70	60	50	40	30	20	10	0
ϵ	0.575	0.536	0.520	0.512	0.505	0.499	0.494	0.489	0.485	0.481	0.476
$y = \epsilon^3/(1-\epsilon)^2$	1.052	0.715	0.610	0.564	0.526	0.495	0.471	0.448	0.430	0.413	0.393
$\int_{p_z}^{100} y dp_z$	0	8.31	14.85	20.72	26.17	31.27	36.10	40.69	45.08	49.30	53.33
x/L	0	0.156	0.278	0.389	0.490	0.588	0.676	0.764	0.845	0.916	1.000



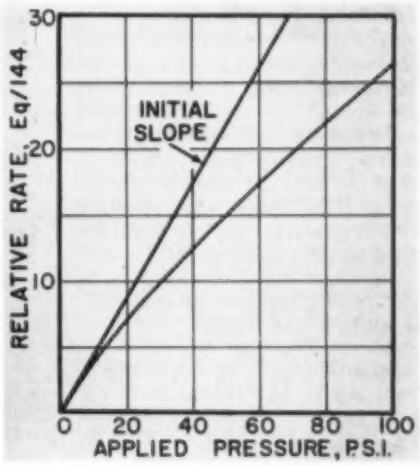


Fig. 11. Left, Variation of pressure in a filter cake.

Fig. 12. Above, Rate of flow vs. applied pressure.

Dividing (18) by (19) gives

$$\frac{x}{L} = \frac{\int_{P_z}^{P} y dP_z}{\int_{P_1}^{P} y dP_z} \qquad (20)$$

where $y = \epsilon^3/(1-\epsilon)^2$. Equation (20) states that the value of P_z for a given applied pressure P depends only on x/L and not on q, μ, or S_o.

In order to solve Equations (18)-(20) it is necessary to relate ϵ to P_z as was previously done in Figure 10. With this information it is possible to obtain the value of the Kozeny function $\epsilon^3/(1-\epsilon)^2$ for each P_z and numerically to integrate Equations (18)-(20).

EXAMPLE 1. Suppose a liquid is to flow through a fixed bed of the kaolin for which ϵ vs. p_z is plotted in Figure 10. Calculations for obtaining the p_z vs. x/L relationship at 100 lb./sq.in. are shown in Table 3.

A plot of the data in Table 3 for an applied pressure of 100 lb./sq.in. is shown in Figure 11 along with curves for 25, 50, and 75 lb./sq.in. While the curves do not depart greatly from straight lines, there is definite curvature. On the 100 lb./sq.in. curve, the slope at $x/L = 1.0$ is about 2.4 times the slope at $x/L = 0$.

Rate of Flow vs. Applied Pressure

Of more interest than the pressure drop throughout a fixed bed is the variation of the rate of flow with the applied pressure. Consider a rectangular solid of constant thickness L in which the liquid flows in one surface and out the opposite. Suppose the total mass of dry solid is w lb./sq.ft. If ϵ represents the per cent voids at distance x below the surface and the true density is ρ_s, then the mass of solids per square foot in distance dx is given by

$$dw = (\text{density})(\text{volume of solids})$$

$$= \rho_s(1-\epsilon)dx \qquad (21)$$

where $(1-\epsilon)dx$ represents the true volume of the solids. Integrating from zero to L yields

$$w = \rho_s \int_0^L (1-\epsilon)dx \qquad (22)$$

The variable of integration in (22) can be changed from x to P_z with the aid of the Kozeny equation (16). The differential dx is obtained from (16) and substituted into (22). The limits of integration are changed from L to P_1 and O to P. Thus combining (16) and (22) and changing the limits of integration to avoid a negative sign leads to

$$q = \frac{\rho_s g_c}{k\mu w S_o^2} \int_{P_1}^{P} \frac{\epsilon^3}{(1-\epsilon)} dP_z \qquad (23)$$

The value of this integral can be found graphically in a manner similar to that used in Example 1. A plot of a relative rate $k\mu w S_o q/\rho_s g_c = qE$ vs. P for the solid of Example 1 is shown in Figure 12. It can be seen that the decrease in the porosity with increasing pressure has a pronounced effect on the flow rate. Calculations show that the average resistance defined as P/q at 100 lb./sq.in. is 1.5 times the resistance at 5 lb./sq.in.

Two Solids in Series

If the liquid is flowing through two solids in series as would occur with two layers of graded sand or a precoat in filtration, Equation (23) must be modified. Suppose that the pressure drops

from P to P_1 in the first solid and from P_1 to P_2 in the second solid, where P_2 is now the pressure required to overcome the septum resistance. Equations similar to (23) can be set up for each solid subject to the condition that the flow rate is the same through each. Thus

$$q = \frac{g_c \rho_1}{k\mu w_1 S_1^2} \int_{P_1}^{P} \frac{\epsilon_1^3}{(1-\epsilon_1)} dP_x$$

$$= \frac{g_c \rho_2}{k\mu w_2 S_2^2} \int_{P_2}^{P_1} \frac{\epsilon_2^3}{(1-\epsilon_2)} dP_x \quad (24)$$

where the subscripts 1 and 2 are used to denote the values of the parameters ϵ, ρ, w, and S_o for the two solids. Theoretically, P_1 can be eliminated from these two equations to give q as a function of the inlet and outlet pressures P and P_2. If both solids were incompressible and ϵ_1 and ϵ_2 were constants, integration of (24) would produce

$$\frac{k\mu q}{g_c} = \frac{\rho_1}{w_1 S_1^2} \frac{\epsilon_1^3}{(1-\epsilon_1)} (P - P_1)$$

$$= \frac{\rho_2}{w_2 S_2^2} \frac{\epsilon_2^3}{(1-\epsilon_2)} (P_1 - P_2) \quad (25)$$

Elimination of P_1 yields

$$q = \frac{g_c (P - P_2)}{(w_1 a_1 + w_2 a_2)} \quad (26)$$

where

$$a_1 = \frac{k(1-\epsilon_1) S_1^2}{\rho_1 \epsilon_1^3} \quad (27)$$

and

$$a_2 = \frac{k(1-\epsilon_2) S_2^2}{\rho_2 \epsilon_2^3} \quad (28)$$

The quantities a_1 and a_2 are the resistances per pound mass per square foot of solid. If the porosities are not constant, it is necessary to perform the integrals in (24) by numerical methods and adjust the value of P_1 so that the equality is realized.

Constant Rate Filtration

In the previous sections the analysis has been simplified in that the thickness and the mass of cake have not changed with time. In a filtration process, the thickness changes with time; and the equations must be modified. Fundamentally, it is desired to obtain relationships between the volume filtered, pressure, and time.

If the filtration is carried out at constant rate, the mass of material deposited per square foot w and the applied pressure P which is the upper limit of the integrals in Equations (23) and (24) will vary together. As w increases in Equation (23) or (24), the value of P must also increase if q remains constant. If v is the volume of filtrate per square foot, m the average ratio of the mass of wet to dry cake, and s the per cent solids in the slurry, then

$$w = s\rho v/(1 - ms) = s\rho q\theta/(1 - ms) \quad (29)$$

where θ is the time and $v = q\theta$. In the case of a dilute slurry where $(1 - ms)$ is approximately unity, (29) reduces to

$$w = s\rho v = s\rho q\theta \quad (30)$$

Combining (29) with (23) gives

$$\frac{s\rho\mu}{1 - ms} \frac{kS_o^2}{\rho_s g_c} q^2\theta = \int_{P_1}^{P} \frac{\epsilon^3}{(1-\epsilon)} dP_x \quad (31)$$

This equation represents the desired solution for constant rate filtration in which θ is given as a function of the upper limit P. The lower limit P_1 is constant only when the septum resistance does not change, e.g., when the solids are laid down directly on something like a wire screen. If a precoat is involved, the changing pressure P would cause the precoat resistance to increase, and P_1 would not be constant. If P_1 is small, slight changes would have little effect on the results.

If s is not small enough so that ms may be neglected, m must be obtained by an integration. Thus

$$m = \frac{\text{mass wet cake}}{\text{mass dry cake}}$$

$$= 1 + \frac{\text{mass moisture}}{\text{mass dry cake}} \quad (32)$$

$$m = 1 + \frac{\rho \int_o^L \epsilon dx}{\rho_s \int_o^L (1-\epsilon) dx} \quad (33)$$

Substituting for dx as obtained from Kozeny's equation yields

$$m = 1 + \frac{\rho \int_{P_1}^{P} \frac{\epsilon^1}{(1-\epsilon)^2} dP_x}{\rho_s \int_{P_1}^{P} \frac{\epsilon^3}{(1-\epsilon)} dP_x} \quad (34)$$

When ϵ does not vary too widely, Equation (34) may be replaced by

$$m = 1 + \frac{\rho\epsilon}{\rho_s(1-\epsilon)} \quad (35)$$

which is usually sufficiently accurate if an average value of ϵ for liquid pressures between P_1 and P is used.

For the case of constant porosity, integration of (31) gives the usual simple form of the constant rate equation. Thus

$$P - P_1 = \frac{s\rho\mu}{1 - ms} \frac{a}{g_c} q^2\theta \quad (36)$$

where a, the filtration resistance, is given by

$$a = \frac{k(1-\epsilon)S_o^2}{\rho_s \epsilon^3} \quad (37)$$

Equation (36) would only be valid for an incompressible solid in which the voids were independent of the pressure.

EXAMPLE 2. Suppose a solid having the same porosity characteristics as the kaolin in Example 1 is to be filtered in a unit with negligible septum resistance at a constant rate of 0.5 gal./(min.)(sq.ft.). Further suppose that the slurry is dilute and contains 0.5% solids by weight. Other parameters have the values:

μ = 1 centipoise
ρ = 62.4 lb.m./cu.ft.
ρ_s = 124.8 lb.m./cu.ft.
S_o = 2,000,000 sq.ft./cu.ft.
θ' = min. = $\theta/60$

Since s = 0.005, ms will be small, and $(1 - ms)$ may be taken as unity. Changing the rate from gallons per minute to consistent units yields a value of $(0.5)/(60)(7.48) = 0.00113$ cu.ft./(sec.)(sq.ft.). Substituting the values in (31) yields

$$\frac{(0.005)(62.4)(0.000672)(5)(4)(10^{12})(0.00113)^2(60)\theta'}{(124.8)(32.2)}$$

$$= 77.8\theta' = \int_o^P \frac{\epsilon^3}{(1-\epsilon)} dP_x \quad (38)$$

In (38) P is in pounds per square foot. Changing to pounds per square inch leads to

$$\theta' = 1.85 \int_o^P \frac{\epsilon^3}{(1-\epsilon)} dp_x \quad (39)$$

Table 4

p_x	0	10	20	30	40	50	60	70	80	90	100
ϵ	0.575	0.536	0.520	0.512	0.505	0.499	0.494	0.489	0.485	0.481	0.476
p_s	100	90	80	70	60	50	40	30	20	10	0
$\frac{\epsilon^3}{1-\epsilon}$	0.448	0.331	0.292	0.275	0.260	0.248	0.238	0.228	0.222	0.213	0.206

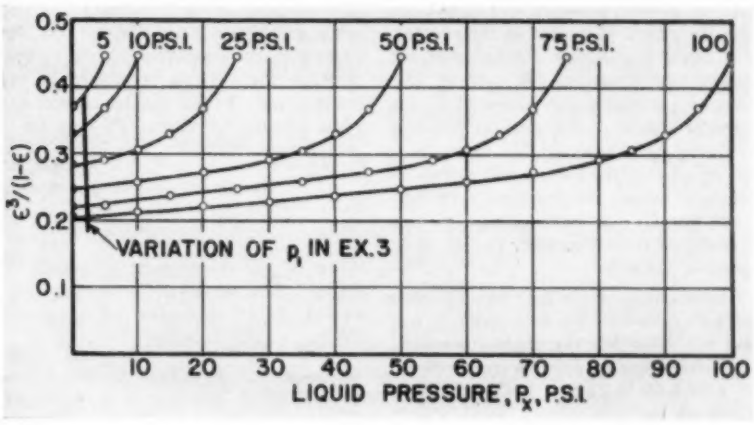


Fig. 13. Variation of the Kozeny function with liquid pressure.

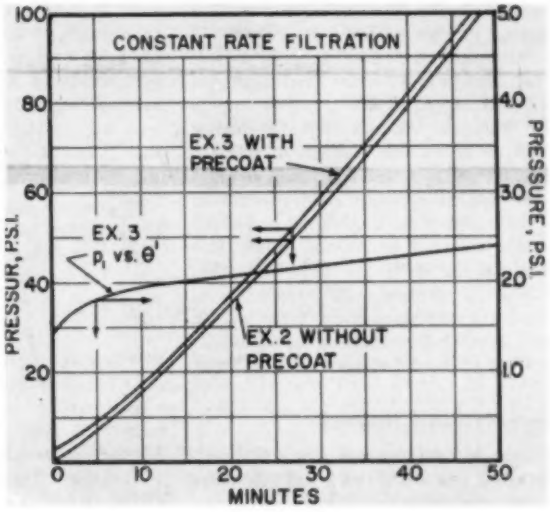


Fig. 14. Pressure vs. time in constant rate filtration.

For each applied pressure p, the integral must be evaluated numerically to give the time. In Table 4, the calculations are illustrated for p = 100 lb./sq.in.

The integral corresponding to Equation (31) is found by calculating the area under the curve of $\epsilon^3/(1-\epsilon)$ plotted against p_x. The graphs of $\epsilon^3/(1-\epsilon)$ vs. p_x for applied pressures ranging from 5-100 lb./sq.in. are demonstrated in Figure 13. The area under the curve for 100 lb./sq.in. is found to be 26.39 lb./sq.in. or 3800 lb./sq.ft. The time required to reach 100 lb./sq.in. is obtained from Equation (39) and is $\theta' = (1.85)(26.15) = 48.3$ min. In Figure 14, the applied pressure is plotted against the time. The curve for Example 2 is typical of the type encountered in the constant rate filtration of a compressible material.

Constant Rate Filtration with a Precoat

Equation (24) for two fixed beds of solids in series can be modified to give the equations for constant rate filtration with a precoat. The mass of solids per square foot w_2 of the precoat will remain constant while w_1 will change with the time in accord with Equation (29). Solving for w in (29) and substituting the result in (24) in the place of w. gives

$$q = \frac{g_c(1-ms)\rho_1}{k\mu s\rho q\theta S_1^2}\int_{P_1}^{P}\frac{\epsilon_1^3}{(1-\epsilon_1)}\,dP_x = \frac{g_c\rho_2}{k\mu w_2 S_2^2}\int_{P_2}^{P_1}\frac{\epsilon_2^3}{(1-\epsilon_2)}\,dP_x \qquad (39)$$

The value of P_2 will equal $\mu R_m q/g_c$ if the septum resistance does not change and the flow is viscous, while P_1 will increase as the filtration process continues. For incompressible solids (39) becomes on integration

$$\frac{k\mu q}{g_c} = \frac{(1-ms)\rho_1}{s\mu q\theta S_1^2}\,\frac{\epsilon_1^3}{(1-\epsilon_1)}\,(P-P_1) = \frac{\rho_2}{w_2 S_2^2}\,\frac{\epsilon_2^3}{(1-\epsilon_2)}\,(P_1-P_2) \qquad (40)$$

In terms of a_1 and a_2 as defined by Equations (27) and (28), Equation (40) may be transformed into

$$q = \frac{1-ms}{s\rho q\theta}\,\frac{g_c(P-P_1)}{a_1} = \frac{g_c(P_1-P_2)}{a_2 w_2} \qquad (41)$$

Elimination of P_1 and substitution of $\mu R_m q$ for $g_c P_2$ yields

$$g_c P - \mu(R_m + w_2 a_2)q = \frac{s\rho\mu}{1-ms}\,a_1 q^2\theta \qquad (42)$$

The solution of Equation (39) in the most general case requires the numerical determination of P_1 and θ for each applied pressure P. The determination of the exact solution is rather tedious unless the simplifying assumption is made that the porosity of the precoat is constant. If P_1 is not large, the variation of P_x and ϵ_2 through the precoat will be small. The porosity will be at its minimum value at the side where the liquid exits. As a satisfactory approximation the value of ϵ_2 may be taken as constant at its minimum value and can be calculated on the basis of the maximum value of P_x. At the side where the filtrate leaves the precoat and $p_x = p_2$, p_x is at a maximum and is given by

$$p_x = p - p_2 \qquad (43)$$

The value of ϵ_2 corresponding to this value of p_x may be calculated by using Equation (4)

$$\epsilon = \epsilon_0(p-p_2)^{-c} \qquad (44)$$

or it may be obtained directly from the experimental data. Since ϵ_2 is being assumed constant, the value of P_1 may be determined from Equation (41), thus

$$P_1 = P_2 + \mu w_2\,\frac{k(1-\epsilon_2)S_2^2}{g_c\rho_2\epsilon_2^3}\,q = P_2 + \mu w_2\,\frac{a_2}{g_c}\,q \qquad (45)$$

Values of ϵ_2 and a_2 will change during the course of the filtration. As the filtration pressure P builds up, the value of ϵ_2 will decrease and a_2 will increase. With the values of P and P_1 fixed, θ is found to be

$$\theta = \frac{(1-ms)}{\mu s\rho q^2}\,\frac{g_c\rho_1}{kS_1^2}\int_{P_1}^{P}\frac{\epsilon_1^3}{(1-\epsilon_1)}\,dP_x \qquad (46)$$

EXAMPLE 3. Suppose a heavy precoat of 1.0 lb./sq.ft. of a filter aid with the following characteristics is laid down upon a septum with negligible resistance:

sp.gr. = 2.3
S_2 = 1,000,000 sq.ft./cu.ft.
$\epsilon_2 = 0.85\ p_x^{-0.015}$

Further suppose that the material of Example 3 is being filtered under the following conditions

which are identical with those of the previous example:

sp.gr. = 2.0
S_1 = 2,000,000 sq.ft./cu.ft.
s = 0.005
$1 - ms$ = 1.0 (approximately)
q = 0.5 gal./min./(sq.ft.)
μ = 1 centipoise
ρ = 62.4 lb.m./cu.ft.
p_2 = 0
θ' = min.

On changing to lb./sq.in. and minutes, Equation (39) becomes

$$0.00112 = \frac{0.00103}{\theta'} \int_{p_1}^{p} \frac{\epsilon_1^3}{(1-\epsilon_1)} dp_x$$

$$= 0.000197 \frac{\epsilon_2^3}{(1-\epsilon_2)} p_1 \qquad (47)$$

where p_1 is in pounds per square inch and ϵ_2 is the value of the porosity corresponding to the solid pressure at the liquid exit from the precoat. Equations (45) and (46) become

$$p_1 = \frac{(0.000672)(5)(10^{12})(0.00112)}{(32.2)(2.3)(62.4)(144)} \frac{1-\epsilon_2}{\epsilon_2^3}$$

$$= 5.66 \frac{1-\epsilon_2}{\epsilon_2^3} \qquad (48)$$

$$\theta' = 1.85 \int_{p_1}^{p} \frac{\epsilon_1^3}{(1-\epsilon_1)} dp_x \qquad (49)$$

The value of θ' in minutes corresponding to the applied pressure p in pounds per square inch as given by (49) can be obtained by graphical integration of $\epsilon_1^3/(1-\epsilon_1)$ between p_1 and p. Since the solid being filtered is the same as that used in Example 2, the value of $\epsilon_1^3/(1-\epsilon_1)$ will be the same for equal values of p_x, and the curves of Figure 13 may be employed for obtaining the values of the integrals. In Example 2, where there was no precoat and negligible septum resistance, the integration was carried out with the lower variable of integration in (49) equal to zero. In this example, the lower limit of integration will not be zero, and the numerical value of the integral in this example will be smaller for a given applied pressure p than in the previous example. This amounts to saying that the time required to reach a given pressure will be smaller with the added resistance of the precoat.

In order to calculate the value of the integral in Equation (46), it is first necessary to obtain the values of p_1 for different values of the applied pressure p. Since p_2 is zero in this example p_s will equal p at the outlet, and ϵ_2 can be calculated from the relation $\epsilon_2 = 0.85\, p_s^{-0.015} = 0.85\, p^{-0.015}$. With ϵ_2, p_1 can be obtained from Equation (4) as illustrated in Table 5.

Examination of the first two columns in Table 5 reveals the fact that p is less than p_1. Since p is the applied pressure, it must be greater than or equal to p_1. At $p = 1.46$ lb./sq.in., both p and p_1 are equal, and the time is zero. Therefore 1.46 lb./sq.in. represents the initial pressure necessary to overcome the resistance of the precoat. In Figure 14 the variation of p_1 with time is shown. When the total pressure had increased to 100 lb./sq.in., p_1 had changed to only 2.37 lb./sq.in. Actually with a smaller and more reasonable quantity of precoat, the values of p_1 would have been smaller.

The applied pressure for the filtration of the solid with a precoat is plotted against the time in Figure 14 and can be compared with the same filtration without a precoat. Although p_1 is actually a variable, little error would have ensued from having assumed p_1 constant and equal to about 2.0 lb./sq.in.

Constant Pressure Filtration

If the applied pressure P remains constant, the rate of filtration will decrease as the cake thickness builds up. Equation (25) can be adapted to a constant pressure filtration if $q\theta$ is replaced by v and q by $dv/d\theta$. Thus

$$\frac{s\rho\mu}{(1-ms)} \frac{kS_o^2}{g_c p_s} v \frac{dv}{d\theta} = \frac{v dv}{C d\theta}$$

$$= \int_{P_1}^{P} \frac{\epsilon^3}{(1-\epsilon)} dP_x \qquad (50)$$

where C represents the combined value of the constants on the left-hand side of the equation. Conditions for solving (50) will differ from those of constant rate filtration in that the upper limit of the integral P will remain constant while $dv/d\theta$ and P_1 will both vary. Two cases present themselves depending upon whether the septum resistance is constant or not. In the simpler case of constant septum resistance, P_1 may be replaced by

$$g_c P_1 = \mu R_m \frac{dv}{d\theta} \qquad (51)$$

where R_m is the septum resistance and viscous flow through the septum is assumed. If ϵ is constant, on integration Equation (50) becomes

$$\frac{\alpha \rho_s \mu}{g_c(1-ms)} v \frac{dv}{d\theta} = P - P_1$$

$$= P - \frac{1}{g_c} \mu R_m \frac{dv}{d\theta} \qquad (52)$$

where α is defined by Equation (33). Integration of (52) leads to the usual parabolic relation of v to θ expressed as

$$\frac{\alpha \rho_s \mu}{g_c(1-ms)} \frac{v^2}{2} + \frac{1}{g_c} \mu R_m v = P\theta \qquad (53)$$

If ϵ is not constant, a graphical integration must be carried out to obtain the v vs. θ relationship. It is possible to solve for the volume in Equation (50) to obtain

$$v = \frac{C}{dv/d\theta} \int_{\frac{1}{g_c}\mu R_m \frac{dv}{d\theta}}^{P} \frac{\epsilon^3}{(1-\epsilon)} dP_x \qquad (54)$$

Since P is fixed, the value of the integral will depend upon the lower limit or $dv/d\theta$. Thus, the integral is a function of $dv/d\theta$. It is possible to choose values of $dv/d\theta$ and then calculate v. The value of θ then can be obtained by a second numerical integration as illustrated in the following example.

EXAMPLE 4. The solution of Equation (50) will be carried out for the same solid used in Examples 2 and 3. Suppose the applied pressure is 100 lb./sq.in., the product $\mu R_m/g_c = (10{,}000)(144)$ or simply 10,000 when the pressure is in pounds per square inch and $C = 1.16\ (10^{-6})$. In order to solve this problem, various values of $dv/d\theta$ will be chosen, thus fixing P_1 and the limits on (54). The initial rate of filtration is such that all the pressure drop is across

Table 5

p, applied pressure	1.0	1.2	1.46	5	10	25	50	75	100
ϵ_2	0.85	0.849	0.845	0.829	0.821	0.811	0.802	0.797	0.792
$\epsilon_2^3/(1-\epsilon_2)$	4.09	4.04	3.90	3.33	3.09	2.82	2.61	2.50	2.26
p_1, lb./sq.in.	1.38	1.40	1.46	1.70	1.83	2.01	2.17	2.26	2.37
$\int_{p_1}^{p} \frac{\epsilon_1^3}{(1-\epsilon_1)} dp_x$	.....	.....	0	1.37	3.16	7.71	14.34	20.27	25.66
θ', min.	.....	.....	0	2.54	5.85	14.3	26.5	37.5	47.5

the septum, and $p_2 = p = 100$ lb./sq.in. Thus

$$\frac{dv}{d\theta}\text{ (initial)} = \frac{g_c p}{\mu R_m} = \frac{100}{10{,}000} = 0.01 \text{ ft./sec.} \tag{55}$$

This initial flow rate corresponds to 4.5 gal./min./(sq.ft.). If θ' is given in minutes and p_s in pounds per square inch (54) becomes

$$v = \frac{0.01}{dv/d\theta} \int_{10{,}000 \frac{dv}{d\theta}}^{100} \frac{\epsilon^3}{1-\epsilon}\, dp_s \tag{56}$$

where $0.01 = (144)(60)(1.16)(10^{-6})$. Calculations for obtaining v vs. $dv/d\theta$ from (56) are shown in Table 6. The 100 lb./sq.in. curve for $\epsilon^3/(1-\epsilon)$ vs. p_s in Figure 13 can be used for evaluating the integral of Equation (56).

Table 6

$\frac{dv}{d\theta'}$, ft./sec.	.01	.0095	.009	.0075	.005	.0025
$\frac{dv}{d\theta'}$, ft./min.	0.6	0.54	0.57	0.45	0.30	0.15
P_1	100	95	90	75	50	25
$\int_{P_1}^{100} \frac{\epsilon^3}{(1-\epsilon)} dp_s$	0	2.012	3.77	8.28	14.88	20.77
v	0	0.353	0.698	1.841	4.96	13.83
θ' (min.)	0	0.6	1.2	3.6	12.4	57.6

Plots of $d\theta'/dv$ vs. v as well as lines of constant θ' are shown in Figures 15 and 16. It can be seen in Figure 15 that the lines of $d\theta'/dv$ vs. v are virtually straight, a fact that has frequently been demonstrated experimentally. In analytical form the straight lines in Figure 15 may be represented by

$$\frac{d\theta}{dv} = \frac{2}{K} v + b \tag{57}$$

which integrates into

$$K\theta = v^2 + Kbv \tag{58}$$

Equation (58) is simply the equation of the well-known filtration parabola. Thus the graphical procedure of Example 4 for a compressible solid confirms the fact that constant pressure filtration data can be accurately represented by a parabola. There is, however, a deviation from the parabolic form at the start of the filtration where v is zero.

In Figure 16 the line for 10 lb./sq.in. is shown on an enlarged scale in order to illustrate the deviation from linearity in the $d\theta'/dv$ relationship at the beginning of the filtration. The line which is indicated as coming from Figure 15 represents the straight line through the points for times greater than 20 min. It is apparent that for the points up to 20 min. a line of smaller slope could be constructed. Since the slope is smaller at the beginning of the filtration, the resistance must increase as the filtration proceeds. An average slope up to 20 min. is 25.5 min./(ft.)^6; whereas, the final limiting value of the slope is 25.9. The value of 25.9 corresponds to a filtration resistance of $4.16(10^{11})$ ft./lb. mass.

The initial slope and filtration resistance cannot be calculated with certainty as can be seen from Figure 17. In this figure, the Kozeny function $\epsilon^3/(1-\epsilon)$ is plotted against the liquid pressure for an applied pressure of 10 lb./sq.in. The cross-hatched area under the curve between 6.0 and 10 lb./sq.in. represents the value of the integral in Equation (54). In this region the liquid pressure falls from 10 to 6.0 lb./sq.in. in the cake and from 6.0 to zero across the filter medium. The area under the curve cannot be determined with certainty in the portion of the curve between 8.58 and 10 lb./sq.in. since an extrapolation of the experimental data is necessary as indicated by the dotted extension of the curve. The porosity data were taken from Table 1 with an initial value of $p_a = 1.42(p_s = 10 - 1.42 = 8.58$ lb./sq. in.) and an initial porosity of 0.574 corresponding to $\epsilon^3/(1-\epsilon) = 0.444$. Extrapolation to $p_s = 0$ leads to a value of $\epsilon^3/(1-\epsilon) = 0.508$ for which $\epsilon = 0.592$. In this region of low compressive pressure, the solids may be quite plastic; and it is difficult to obtain the porosity-pressure relations with accuracy. Therefore, there is an initial region of uncertainty in evaluation of the volume-time relationship. As time progresses, the relative effect of this region becomes smaller. The double-hatched region from 8.58 to 10 lb./sq.in. has an area of 0.045 while the total area from zero to 10 lb./sq.in. is 3.86 lb./sq.in. Thus the uncertainty becomes quite small as the volume of filtrate increases.

The initial filtration resistance can be calculated from Equation (37) using the initial value of $\epsilon^3/(1-\epsilon)$, thus

$$\alpha = \frac{k(1-\epsilon)S_o^2}{\rho_s \epsilon^3} = \frac{(5)(4)(10^{12})}{(124.8)(0.508)}$$
$$= 3.16(10^{11}) \text{ ft./lb.m.} \tag{59}$$

The average filtration resistance at any time can be written as

$$\alpha_p = \frac{kS_o^2}{\rho_s} \frac{\left(P - \frac{1}{g_c}\mu R_m dv/d\theta\right)}{\int_{\frac{1}{g_c}\mu R_m \frac{dv}{d\theta}}^{P} \frac{\epsilon^3}{(1-\epsilon)} dP_s} \tag{60}$$

The ultimate resistance approached as $dv/d\theta$ becomes zero is

$$\alpha_p = \frac{kS_o^2}{\rho_s} \frac{P}{\int_o^P \frac{\epsilon^3}{(1-\epsilon)} dP_s} \tag{61}$$

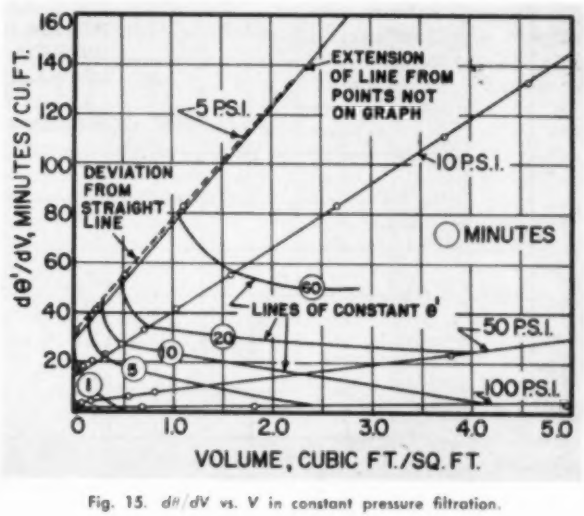


Fig. 15. $d\theta/dV$ vs. V in constant pressure filtration.

For the 10 lb./sq.in. run just considered, Equation (61) becomes

$$\alpha_P = \frac{(5)(4)(10^{12})(10)}{(124.8)(3.86)}$$

$$= 4.16\ (10^{11})\ \text{ft./lb. mass} \qquad (62)$$

This is equal to the value previously found from drawing a tangent through the $d\theta'/dv$ vs. v line. From these calculations it can be seen that the filtration resistance increases approximately 30% above its initial value. Nevertheless, the ultimate value is approached quite rapidly, the average resistance at 20 minutes being within 1.5% of the maximum value. It should be recalled that in the initial stage of the filtration, equilibrium consolidation may not be reached. Since the porosity decreases with time, the initial porosities would be larger than the equilibrium values as reported in Table 1, thus leading to smaller initial resistances than those which have been calculated. From this standpoint, the filtration resistance would be expected to increase more than 30% above its initial value.

Constant Pressure Filtration with Negligible Septum Resistance

The previous method may be simplified somewhat if R_m is taken as zero. If R_m is zero, the value of P_1 representing the lower limit of Equations (50), (54), and (56) will be zero. Thus Equation (50) becomes

$$v\frac{dv}{d\theta} = \frac{1-ms}{s\rho\mu}\frac{g_c\rho_s}{kS_o^2}\int_o^P \frac{\epsilon^2}{(1-\epsilon)}\,dP_x \qquad (63)$$

The right-hand side of Equation (63) is a constant for a given applied pressure P. Thus integration of (63) yields an equation of the form

$$v^2 = K\theta \qquad (64)$$

where the K is identical with the constant in Equation (58). From (64) it can be seen that v and θ are related by a perfect parabola in contrast to the previous case with a finite septum resistance. Again (64) is subject to the limitation of the time effect on consolidation. The filtration resistance found from (63) is not only constant but is also equal to the limiting value given in Equation (61). Thus, as the filter time is increased, the resistance of the medium has a lessening effect on the filtration resistance.

Constant Pressure Filtration with Precoat

The equation for constant rate filtration with a precoat can easily be modified for a constant pressure filtration. In Equation (39), q is replaced by $dv/d\theta$ and $q\theta$ by v, thus

$$\frac{k\mu}{g_c}\frac{dv}{d\theta} = \frac{(1-ms)}{s\rho v}\frac{\rho_1}{S_1^2}\int_{P_1}^{P}\frac{\epsilon_1^3}{(1-\epsilon_1)}\,dP_x$$

$$= \frac{\rho_2}{v_2 S_2^2}\int_{P_2}^{P_1}\frac{\epsilon_2^3}{(1-\epsilon_2)}\,dP_x \qquad (65)$$

With the applied pressure P fixed and $g_c P_2 = \mu R_m dv/d\theta$, the problem rests in finding values of P_1 for various values of v. At the start of the filtration process, the value of P_1 is equal to P, and the maximum pressure is applied to the precoat. Initially then

$$\frac{k\mu}{g_c}\frac{dv}{d\theta} = \frac{\rho_2}{v_2 S_2^2}\int_{\frac{1}{g_c}\mu R_m\frac{dv}{d\theta}}^{P}\frac{\epsilon_2^3}{(1-\epsilon_2)}\,dP_x \qquad (66)$$

To start the solution, a value of $dv/d\theta$ must be found which will satisfy this equality. Smaller values of $dv/d\theta$ are chosen, thereby fixing the left-hand side of (65) and the value of P_2. In the next step P_1 which replaces P in (66) is determined. With P_1 known, the integral of the center member of Equation (65) may be calculated along with values of v. After v has been found as a function of $dv/d\theta$, the values of θ may be determined by graphical integration.

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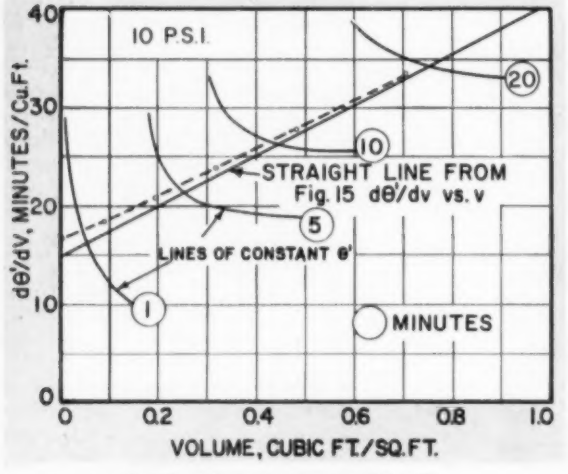

Fig. 16. Above, Enlargement of Fig. 15.

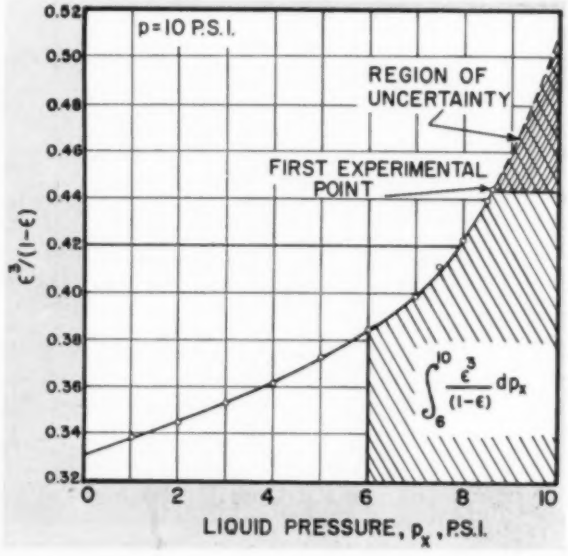

Fig. 17. Right, Integral of Kozeny function in constant pressure filtration.

Notation

A = total area perpendicular to flow, sq.ft.

b = intercept on the graph of $d\theta/dv$ vs. v, reciprocal of the initial rate of filtration, sec. or min./ft.

c = exponent occurring in Equation (4)

C = constant defined by Equation (50)

C_1, C_2 = constants in Equation (5)

D = particle diameter, ft.

E = defined by Equation (23), $k\mu wS_v^2/\rho_l g_c$, cu.ft./(sec.)(lb.f.)

g_c = conversion factor from lb.f. to lbl., numerical equivalent of the standard acceleration of gravity, 32.2 lbl./lb.f.

k = proportionality constant in the Kozeny eq., approximately equal to 5.0

K = twice the reciprocal of the slope of $d\theta/dv$ vs. v, sec. or min./sq.ft.

L = cake thickness, ft.

m = ratio of mass of wet to mass of dry cake

P = applied pressure, lb.f./sq.in.

p = applied presure, lb.f./sq.in.

P_1, P_2 = pressure at liquid exit from solid, lb.f./sq.ft.

p_1, p_2 = pressure at liquid exit from solid, lb.f./sq.in.

P_e = pressure on liquid, lb.f./sq.ft.

p_e = pressure on liquid, lb.f./sq.in.

P_s = pressure on solids, lb.f./sq.ft.

p_s = pressure on solids, lb.f./sq.in.

q = rate of filtration, cu.ft./(sq.ft.)(sec.) or superficial velocity ft./sec.

R_m = resistance of the septum, 1/ft.

R_H = hydraulic radius, ft.

s = per cent solids in slurry

S_v, S_1, S_2 = surface area/cu.ft. of solid material, sq.ft./cu.ft.

u = average velocity of filtrate in voids of filter cake, ft./sec.

v = volume of filtrate/sq.ft., cu.ft./sq.ft.

w, w_1, w_2 = total mass of cake, lb.m./sq.ft.

x = distance measured from filtrate entrance to cake, ft.

y = value of $\epsilon^3/(1-\epsilon)^2$

z = per cent moisture

$\alpha, \alpha_1, \alpha_2$ = filtration resistances, ft./lb.m.

α_p = filtration resistance during constant pressure filtration, ft./lb.m.

$\epsilon, \epsilon_1, \epsilon_2$ = per cent voids or porosity

ϵ_c = dead volume

ϵ_o = per cent voids at one pound per square inch, constant in Eq. (4)

ρ = density of liquid, lb./cu.ft.

$\rho_1, \rho_{l_2}, \rho_2$ = true density of solids, lb./cu.ft.

μ = viscosity, lb.m./(ft.)(sec.)

θ = time of filtration, sec.

θ' = time of filtration, min.

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Discussion

W. H. Elliott, (National Lead Co., Fairhaven, N. J.): In using the Kozeny equation we assume that we have streamlined flow. Is it possible ever to form a bed of solids or a filter cake in which the flow of fluid through the cake is not streamlined and the equation is not applicable?

F. M. Tiller: That is quite possible. In the equations which I showed, I factored out the viscosity term as $1/\mu$, indicating that the velocity was inversely proportional to the viscosity; if we had turbulent flow, the viscosity would be much less important in calculating the resistance which would be proportional to about 0.2 power of the viscosity. We would find also that the velocity would be proportional to the square root of the pressure drop. There is no reason that we couldn't modify the equations for turbulent flow.

Anonymous: Have you ever found any data showing application of the Kozeny equation for highly viscous materials passing through porous beds—materials having a viscosity of 1,000 poises with high pressure drop?

F. M. Tiller: That represents quite a difficult problem. In the first place, many of these liquids with so high a viscosity, particularly like Du Pont viscose, may behave as non-Newtonian liquids. The laws governing the flow rates will not follow the ordinary Kozeny equation. That is a problem which I don't think has been completely solved. There are many other problems which are side products of the filtration of highly viscous materials. It is difficult to tell when the filtrate has been properly clarified and to evaluate filter aid characteristics.

Anonymous: Would you expect sand to compress under pressures of possibly 3,000 or 5,000 lb./sq.in.?

F. M. Tiller: Yes, you certainly would. In fact, you'd probably have crushing of the particles with pressures of that magnitude. Most of the work on sands, clays, and similar materials, has been done by men in the soil mechanics field. As to whether sand is compressible or not depends largely upon particle size. Many fine sands are compressible. In fact, the differentiation between clay and sand is primarily based on particle size.

W. O. Webber (Humble Oil & Refining Co., Baytown, Tex.): In these derivations porosity is assumed to be a single valued function of pressure; that is, the time required to reach equilibrium is assumed to be quite short. In other words, one can see that even with a cake, possessing a significant variation of porosity with pressure, as the cake is laying itself down on the bed and approaching its equilibrium porosity, an amount of time would be required that is significant with respect to the amount of filtrate flowing. Presumably this factor would increase the effective porosity of the cake. Have you considered time lag and eliminated it as being an insignificant item?

F. M. Tiller: No, we certainly haven't eliminated it as an insignificant item. You'll find that there is a general assumption here that the equilibrium porosity is obtained instantaneously, and that is not true. Figure 4 shows the variation of porosity with time. For materials like calcium carbonate, filter aids, etc., you'll find it takes about ten minutes to reach an initial equilibrium after which a gradual creep continues for quite some time. With materials like natural clays, it may take 24 hr. to reach the initial equilibrium with the creep going on continually. Actually, the equations presented at the present time, represent the first approximation, and we can hope that the next set of equations will include the time effect. There are not many data on the time effect. It is important practically inasmuch as the porosity is at a maximum when the bed is laid down and the resistance is at a minimum. In the initial states, you may have a smaller resistance than you will have after the equilibrium porosity has been reached.

Anonymous: In the operation of a Schriver plate and frame-type press or a Sweetland leaf-type press, would your remarks about controlling the pressure of the liquid indicate that longer operation of the filter without cleaning the leaves or plate or more rapid filtration could be obtained by keeping a relatively high back pressure on the liquid leaving the unit?

F. M. Tiller: The compressibility of the solids is dependent upon the pressure drop of the liquid through the solid. If there is point contact between particles, it will not make any difference as far as the compressive pressures are concerned, whether there is a pressure drop from 10 lb. to 0 lb. or 100 lb. to 90 lb. through the cake. The resistance should essentially be the same.

Presented at A.I.Ch.E. Forty-fifth annual meeting, Cleveland, Ohio.

Factors Influencing the Properties of Spray-Dried Materials

J. A. Duffie and W. R. Marshall, Jr.

University of Wisconsin, Madison, Wisconsin

Part II

Drying Studies

EXPERIMENTAL PROCEDURES

Studies were made of the effect of air temperature, feed temperature, and feed concentration on the bulk density of a water-dispersible dye, the effect of air temperature and feed temperature on the bulk density of sodium silicate, and the effect of feed temperature on the bulk density of sodium chloride. In addition, the physical properties of a number of spray-dried materials were observed and compared by microscopic studies. The experimental results are tabulated in Tables 2, 3, 4, and 5. The experimental procedures are discussed below.

After a 4-hr. warm-up period to bring the experimental drying tower to equilibrium, water was introduced to the capillary nozzle ahead of the feed solution, and the pattern of drops was observed at the tower outlet. By means of a traversing mechanism, the nozzle was centered until the water drops fell as nearly in line with the tower axis as possible. Running the tower first with water made it possible to adjust the drop stream before solids entered the tower and hit the walls, and also prevented drying out of solids in the capillary tip. After all the water had run through, feed solution immediately followed, and the run was considered started. The feed temperature was usually adjusted after the run began, and 5 to 10 min. was generally sufficient for the feed preheater to bring the feed to any desired temperature. When the desired air and feed temperature had been attained and the drops had fallen for a few minutes, product samples were taken.

The chief disadvantage of the experimental procedure and the equipment was the fact that the smallest drops obtainable with the viscous jet atomizer were still too large to dry in 20 ft. of fall unless rather high air temperatures were used. The lowest temperature that could be used therefore was about 300° C. Operation of this tower below 300° C. required drop sizes less than 150μ in diam. Since jets from capillaries break up to give drops roughly from 1.5 to 3 times the capillary diameter, the use of small tubes less than 80μ is required. Such small diameters, however, introduce extreme experimental difficulties. Other methods therefore must be developed for producing small drops of controlled diameter, and several have been proposed in recent literature (*2a*, *2b*).

The temperature drop in the air due to evaporation was small, on the order of 10° C., compared with the temperature drop due to heat losses. Therefore, heat balances had little significance in these tests.

The air and feed rates were measured with an orifice or venturi meter and with a rotameter, respectively. A uniform air velocity over the tower cross section at the point of air entry was accomplished by the use of a perforated plate, as shown in Figure 2.

The bulk density of the product was determined by measuring the weight of a volume of a product sample as collected and placed in a graduate. It was found that this initial volume usually reduced to a constant volume if the graduate was gently tapped. Microscopic examinations showed that this volume reduction was not due to particle breakage. Therefore, bulk densities for both "as collected" and for "settled" samples were reported. Moisture analyses, when made, were made by oven drying to constant weight at 105° to 110° C.

Microscopic studies were made of all dried products, and photomicrographs taken of representative samples with a photomicrographic camera. The properties noted were hollowness, friability, type of fracture when crushed, and, where possible, wall thickness. Fracturing was usually done by placing a cover glass over particles in the microscope field and applying the least pressure necessary to crush them.

For one of the materials, water-dispersible organic dye, particle-size distribution data were obtained from photomicrographs of the particles taken at a magnification of 26 times. Contact prints were then made and size distributions obtained by counting the number of particles in size groups of approximately 30-μ increments.

FACTORS INFLUENCING BULK DENSITY

Bulk densities were determined in this study by weighing a measured volume of a product. Two volume measurements were made, as noted above, an initial volume after a minimum of handling and a reduced volume which was attained by gently tapping the containers. All samples were treated in this manner and reached a volume which was independent of further handling. The reduction in volume was about 10% for all but two sodium chloride samples. Microscopic examination after this treatment failed to reveal any evidence of particle breakage or collapse. Thus, a reasonably stable and apparently reproducible bed configuration was achieved. Bulk densities, determined on the basis of the initial and final volumes, are reported as ρ_{B1} and ρ_{B2}, respectively, with the latter considered the more useful. The exception to this behavior, sodium chloride, is discussed later.

The dry particles of dye obtained for various drying conditions were excellent subjects for a study of the variation of bulk density with operating variables, since they were attractive, uniform, and spherical in appearance. Particle-size measurements were easily made from photomicrographs of the particles, and moisture analyses were readily made by oven drying. A typical photomicrograph of these beads is shown in Figure 10.

Some observations on the effect of dried-particle size on bulk density might aid in understanding the results and discussion to follow. For a given regular packing of spheres of uniform size, the fraction of voids is independent of the diameter of the spheres and depends only on the configuration of the packing. For the closest possible rhombohedral packing, the void fraction is 0.2595; for the most open (regular) cubic packing it is 0.4764; and for other types of regular packing it lies between these two (*2*). Thus for a product consisting of uniform spherical particles, the bulk density will depend on the particle density, and not on the particle size, for a

Part I of this article appeared in the August issue.

given packing configuration. In the ideal case, therefore, hollowness and to a lesser extent moisture content are of major importance in determining bulk density.

However, in actual practice a spray-dried product will have a range of particle sizes so that the voids between large particles will be occupied by small particles. Consequently, the bulk density will be greater for a product with a range of particle size and a large percentage of small particles than for a product with a narrow size range.

Drying-Air Temperature. The variation of ρ_{B2} with inlet-air temperature for the dye and sodium silicate is shown in Figure 11. The effect of air temperature is believed to be the only effect on bulk density in these experiments, since the jet atomizer was external to the dryer, and hence air temperature did not affect atomization.

In these experiments, made at constant feed temperature, concentration and rate, and constant nozzle size, the mean drop size produced by the atomizer was nearly constant for each material; i.e., the amount of solids per drop or per product particle was nearly constant. Therefore, the product-particle density reduced to a dry basis should have been inversely proportional to the volume or to the cube of the diameter of the spheres produced for given drying conditions. It was indicated above that bulk density should be proportional to particle density for uniform-sized particles in a given bed configuration, and so ρ_{BD} plotted vs. d_v^3 should give a straight line with a negative slope. A plot of the data for the water-dispersible dye, confirming this reasoning, is shown in Figure 12. In this figure, the cube of the volumetric mean particle size is plotted against the bulk density corrected to zero moisture to eliminate differences due to small variations in the final moisture content.

While the sodium silicate particles were not amenable to size measurement, inspection indicated that the particle size increased with increased air temperature. Calculation of the volumetric mean drop size to be expected when atomizing under these conditions indicated that in all cases the drops underwent some expansion during the drying process. The decrease in bulk density with increasing drying-air temperature, then, resulted from an increase in particle size accompanied by a corresponding decrease in wall thickness and particle density.

Feed Temperature. The variation of bulk density with feed temperature was observed for the water-dispersible dye, sodium silicate, and sodium chloride, and

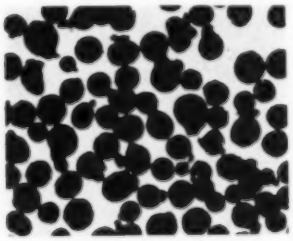


Fig. 10 (a). Particles of dye dried from feed containing 19.5% solids. Mean particle size = 305μ. Run No. 43c.

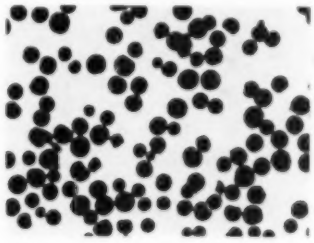


Fig. 10 (b). Particles of dye dried from feed containing 12.6% solids. Mean particle size = 204μ. Run No. 45b.

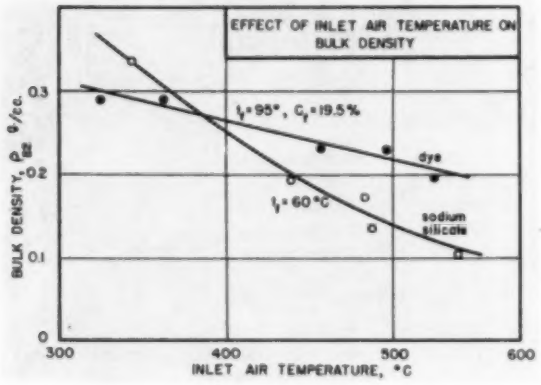


Fig. 11.

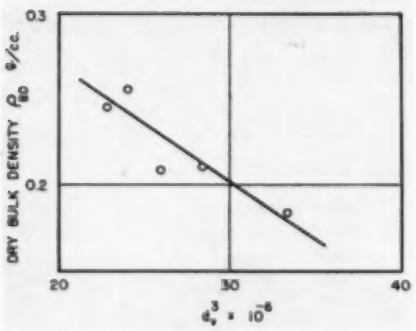


Fig. 12. Correlation of dry bulk density with volume dry particle.

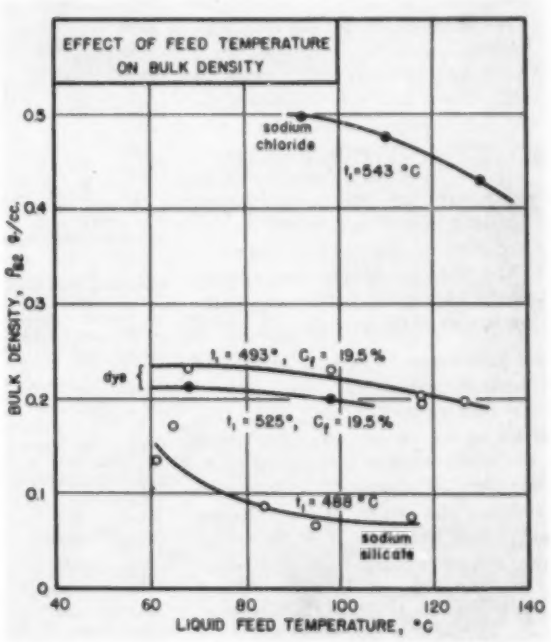


Fig. 13.

the results are shown in Figure 13. Here the change due to feed temperature was complicated by the change in viscosity with temperature, which in turn affected the jet breakup.

For the dye the variation of d_v, the dry-product-particle diameter, with feed temperature was found to be small (Table 3). The effect of temperature on the particle size obtained by atomization, however, was significant. Although the viscosity enters the mean drop-size correlation only to the 0.10 power [Equation (13)], a 40% variation in pressure drop through the nozzle was recorded in these experiments, which indicated a 4% decrease in the geometric mean drop size. This corresponded to a decrease in initial drop volume and thus to a decrease in the amount of solids per dry particle of 11%, which was nearly the decrease in dry-bulk density noted over the range of conditions studied. Thus, if atomization effects are eliminated, the dry-bulk density of this material apparently was not affected by changes in feed temperature per se.

The effect of increasing feed temperature is twofold. First, the feed viscosity is reduced, causing a decrease in mean drop size produced by the atomizer. Second, the initial warm-up period of drying is shortened by preheating, and thus the moisture content of the product may be slightly reduced. If film formation occurs, it may start earlier in the drying process to give a slight increase in particle size. The combined effects may evidently either decrease or increase bulk density, depending on the effect on atomization and the nature of the material involved.

While the trends noted in ρ_{B2} for sodium silicate and the dye were observed for sodium chloride, the conditions of drying were such that the product was not completely free flowing at the lower feed temperatures. As a result, ρ_{B1}, the bulk density before settling, increased with increasing feed temperature. However, the density after settling appeared to be unaffected by any sticking tendencies of the particles.

Feed Concentration. The bulk density of the water-dispersible dye was measured at two feed concentrations. Again the analysis of the results was complicated by the effect of feed concentration on atomization. The striking effect noted on reducing the concentration of the dye from 19.5 to 12.5% solids was a reduction of the mean particle size from about 300 to about 200μ, as shown in Table 4 and in Figure 10. If atomization changes were neglected, the amount of solids per drop, and thus per particle, should have

TABLE 2.—EFFECT OF DRYING-AIR TEMPERATURE ON BULK DENSITY

Run	t_1, °C.	t_2, °C.	ρ_{B1}	ρ_{B2}	Final moisture, % dry basis	ρ_{BD}	d_v, μ
Sodium silicate, 25%, D_N = 130μ, F = 6.25 cu.cm./min.							
36a	438	57	0.136	0.193			
36b	344	59	0.281	0.334			
37	483	65	0.143	0.172			
38a	487	62	0.113	0.135			
40	538	58	0.092	0.107			
Dye AQD 585A, 19.5%, D_N = 105μ, F = 6.25 cu.cm./min.							
43b	523	96	0.172	0.196	6.57	0.184	332
44b	496	98	0.194	0.228	6.70	0.208	295
43c	457	94	0.192	0.231	9.45	0.211	305
43d	362	93	0.238	0.290	12.8	0.257	289
43e	325	94	0.243	0.290	8.00	0.246	284

TABLE 3.—EFFECT OF LIQUID-FEED TEMPERATURE ON BULK DENSITY

Run	t_1, °C.	t_2, °C.	ρ_{B1}	ρ_{B2}	Final moisture, % dry basis	ρ_{BD}	d_v, μ
Dye AQD 585A, C_f = 19.5%, D_N = 105μ, F = 6.25 cu.cm./min.							
44a	495	68	0.188	0.234	10.5	0.212	298
44b	496	98	0.194	0.228	6.70	0.208	295
44c	492	117	0.178	0.203	4.65	0.194	279
44d	491	117	0.173	0.198	3.34	0.191	287
44e	492	126	0.176	0.194	3.0†	0.188	291
Sodium silicate, 25%, D_N = 130μ, F = 6.25 cu.cm./min.							
37	483	65	0.143	0.172			
38a	487	62	0.113	0.135			
38b	491	115	0.0626	0.0726			
41a	490	84	0.0634	0.0842			
41b	495	95	0.0544	0.0667			
Sodium chloride, 25%, D_N = 105μ, F = 6.25 cu.cm./min.							
46a	543	94	0.277	0.497	4.9	0.474	
46b	543	110	0.302	0.476	5.02	0.454	
46c	543	130	0.337	0.432	1.16	0.427	

† Estimated by extrapolation.

TABLE 4.—EFFECT OF FEED CONCENTRATION ON BULK DENSITY

Run	t_1, °C.	t_2, °C.	C_f	ρ_{B1}	ρ_{B2}	Final moisture % dry basis	ρ_{BD}	d_v, μ
Dye AQD 585A, D_N = 105μ, F = 6.25 cu.cm./min.								
45a	489	95	12.5	0.224	0.248	12.0	0.222	204
44b	496	98	19.5	0.194	0.228	6.70	0.208	295
45b	489	116	12.5	0.217	0.247	11.4	0.222	201
44c	492	117	19.5	0.178	0.203	4.65	0.194	279
44d	491	117	19.5	0.173	0.198	3.34	0.191	287

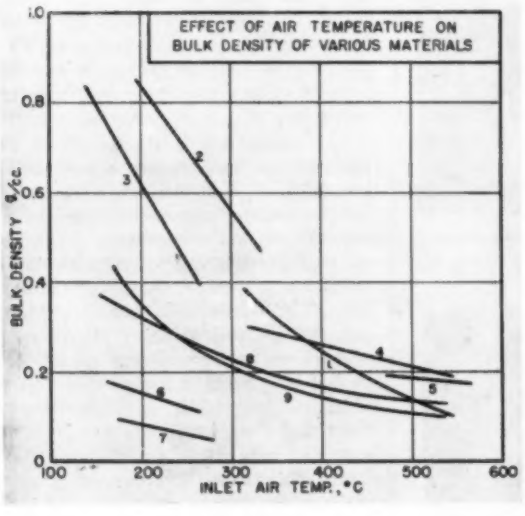
been in the ratio of the concentrations, 19.5/12.5. Based on the data for a feed temperature of 116° C., the volumes of the resulting particles were in the ratio of $(279/201)^3$. The resulting particle densities and thus bulk densities would have then been in the ratio of $(12.5/19.5)(279/201)^3$, or 1.73. The measured ratio was not this high, the difference probably being due to a change in atomization caused by the change in viscosity with concentration and to the greater uniformity of particle size obtained with the more dilute feed, as shown in Figure 10.

Although this reasoning aids in explaining the results obtained, it does not imply that bulk density necessarily increases with a decrease in feed concentration. This can be illustrated by the following ratio of particle densities derivable from Equation (11):

$$\frac{\rho_2}{\rho_1} = \frac{D_{p_2}^3}{D_{p_1}^3} \frac{C_{f_2}}{C_{f_1}} \left(\frac{d_{v_1}^3}{d_{v_2}^3} \right) \qquad (14)$$

where D_p refers to the liquid-drop diameter produced by atomization, and d_v refers to the dry-particle diameter. It is evident from Equation (14) that if an increase in feed concentration increases D_{p_2} more than d_{v_2} or if $D_{p_2} = D_{v_2}$, then the particle density will surely increase. As shown in Figure 6, this is the case for most materials except at high solids contents, $> 70\%$. If atomization can be so adjusted that D_{p_2} and D_{p_1} are nearly equal, then ρ_2 will depend on the ratio $C_{f_2}/d_{v_2}^3$. If this ratio is greater than $d_{v_1}^3/C_{f_1}$, then ρ_2 will increase, while if it is less, ρ_2 will decrease. From the data of Table 4 and Equation (14), the estimated ratio of D_{p_2}/D_{p_1} is 1.15, or the average drop size formed from jet breakup at the higher solids content would be estimated as 15% greater than the drop size for the smaller concentration to account for the observed decrease in bulk density with increase in solids content. Data from the literature indicate that for other materials the opposite effect results from an increased solids content (Figure 16). Certainly, it is well known that with soaps and detergents the bulk density increases with feed concentration. These materials, however, are film-forming products. Thus the product of concentration ratio and reciprocal volume ratio would be greater than unity, as discussed above. Secondary effects such as viscosity on atomization will produce additional changes in bulk density.

Comparison with Other Published Results. Figures 14, 15, and 16 compare the available data on the variation of bulk density with drying-air temperature, feed temperature, and feed concentration. Only the trends of these data should be considered significant as they were obtained in different types of dryers with different atomizers and collection systems. The data of Wallman and Blyth (*19*) are probably the most reliable of the other data shown. Those of Chu, Stout and Busche (*1*) are questionable because of passage of the dried product through a fan prior to bulk-density measurement. The curves of Lamont (*5, 6*) and Jones (*4*) represent incomplete data from patents.



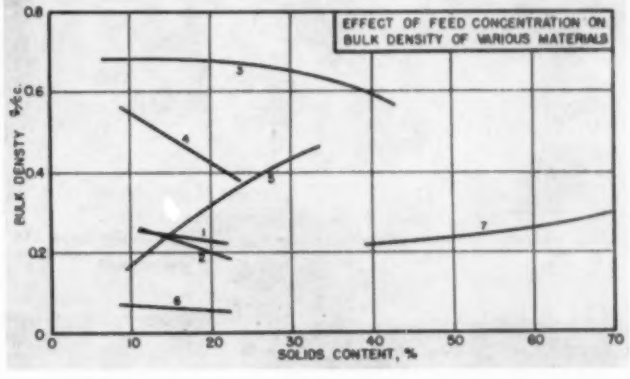


Figure 14. Top left, Correlation of data from literature and this study on effect of air temperature on bulk density.
1. Na_2SiO_3 (25%, t_f = 60° C.). This investigation.
2. Na_2SiO_3 (25%, t_f = 20° C.). Wallman and Blyth (19).
3. Na_2SiO_3 Lamont (12).
4. Dye AQD 585A (19.5%, t_f = 95° C.). This investigation.
5. Marasperse-C (36%, t_f = 80° C.). This investigation.
6. Soap. Lamont (6).
7. Gelatin. Lamont (6).
8, 9. Santomerse (20%). Chu, Stout and Busche (1). (Data at two atomizer pressures.)

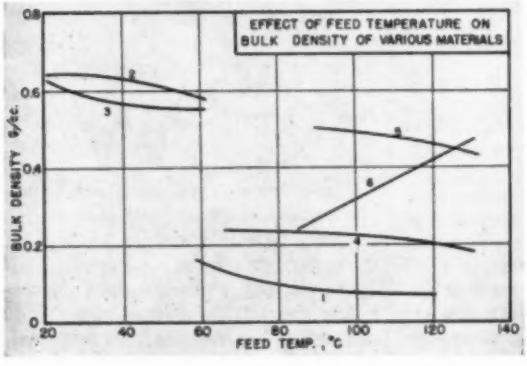


Fig. 15. Bottom left, Inconclusive effect of feed temperature on bulk density.
1. Na_2SiO_3 (25%, t_1 = 488° C.). This investigation.
2. Na_2SiO_3 (40%, t_1 = 260° C.). Wallman and Blyth (19).
3. Na_2SiO_3 (25%, t_1 = 260° C.). Wallman and Blyth (19).
4. Dye AQD 585A (19.5%, t_1 = 493° C.). This investigation.
5. NaCl (19%, t_1 = 543° C.). This investigation.
6. Soap. Lamont (6).

Fig. 16. Top right, Plot of various data showing the variable effect of feed concentration on bulk density.
1, 2. Dye AQD 585A (t_1 = 493° C., t_f = 95°, 116° C.).This investigation.
3. Na_2SiO_3 (t_1 = 260° C., t_f = 20° C.). Wallman and Blyth (19).
4. Na_2SiO_3 Lamont (6).
5. Na_2SiO_3 Reavell (12).
6. Gelatin. Lamont (6).
7. Soap. Jones (4).

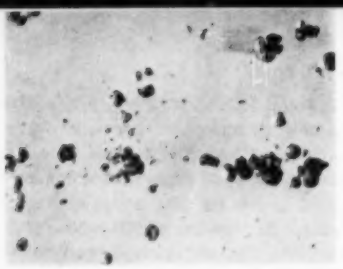


Fig. 17. Dry particles of sodium sulfate, showing crushed and whole spheres. Note the "blown inward" appearance of the blow holes in the uncrushed particles.

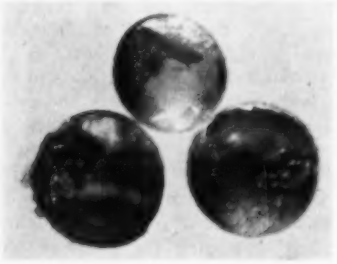


Fig. 18. Large balloon-like particles of potassium nitrate. Shell wall thickness 5-10μ.

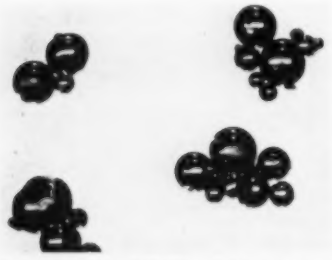


Fig. 19. Solid spherical particles of corn syrup.

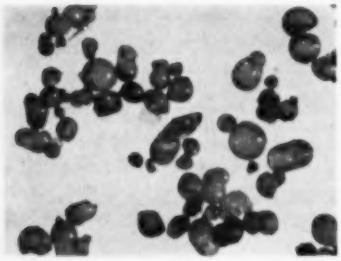


Fig. 20. Dry particles of whole milk.

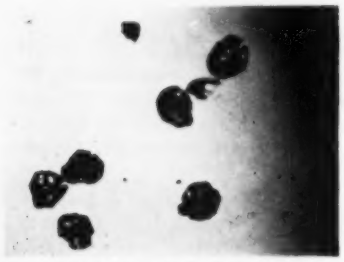


Fig. 21. Shriveled dry particles of gelatin.

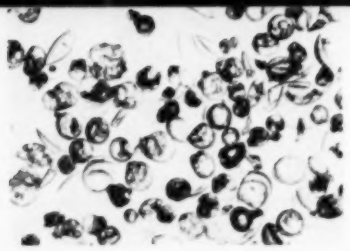


Fig. 22. Sodium silicate. Note how ruptured particles curled up. Subjecting particles to light pressure caused rupturing.

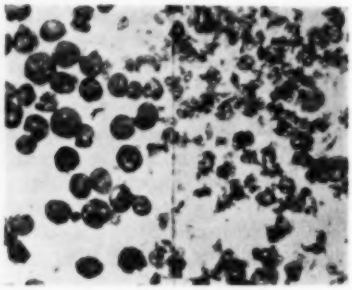


Fig. 23. Potassium sulfate, uncrushed and crushed.

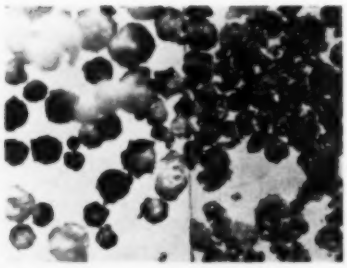


Fig. 24. Uncrushed and crushed particles of sodium chloride.

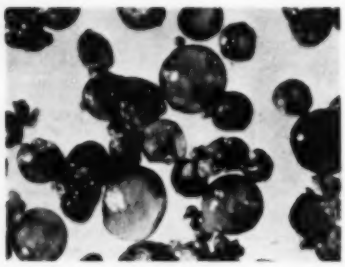


Fig. 25. Hollow beads of dispersing agent (Marasperse-C).

There is general agreement that bulk density decreases with increasing drying-air temperature.

The effect of increasing the feed temperature, in most reported instances, is a slight reduction of ρ_B. Lamont's data for soap are an exception, while Marshall and Seltzer (*8*) report that increasing the feed temperature can increase ρ_B for some materials. These apparently conflicting results are in accord, however, with the results of this study, as discussed above.

The effect of concentration appears to be more difficult to generalize. Much of the available information indicates a decrease in bulk density as solids concentration increases. Marshall and Seltzer reported that hydrophilic materials other than soaps and detergents exhibit a decrease in ρ_B with increasing concentration, but that the reverse is true for non-hydrophilic materials such as salts, dyes, etc. Again these can be reconciled according to the foregoing discussion based on Equation (14).

PHYSICAL CHARACTERISTICS OF SPRAY-DRIED PARTICLES

A number of different materials were dried in the experimental tower and the product particles examined from the standpoint of their appearance, hollowness, mode of fracture under pressure, relative bulk density, and probable degree of dustiness as evidenced by friability. The temperatures employed in these experiments were higher, in some cases, than those used in the commercial drying of the materials for the reasons noted above. However, the results are believed to be significant and indicate a possible classification of the materials on the basis of certain properties of the dried products.

The materials dried in this phase of the investigation included sodium chloride, sodium sulfate, sodium nitrate, potassium nitrate, potassium sulfate, sodium silicate, and ammonium nitrate, a water dispersible organic dyestuff (dye *AQD585A*), a dispersing agent (Marasperse-*C*), whole milk, coffee extract, corn syrup, and gelatin. Microscopic examination of the products was accomplished by placing a few particles on a slide, studying their appearance, and fracturing them by application of light pressure on a cover glass placed over them on the slide. This procedure kept the same particles in view and often permitted direct measurements of the wall thickness. Photomicrographs of typical products are shown in Figures 17 to 25.

The materials studied were classified according to (*a*) their tendency to form hollow particles and (*b*) the type and ease of fracture. The bulk density of each material was studied as a function of the operating variables.

The results of the observations of hollowness, friability, and probable dusting tendencies are tabulated in Table 5 for convenient reference.

On the basis of these results the materials grouped themselves in order of decreasing tendency to form large hollow particles as follows:

1. Sodium silicate, Marasperse-C, and, under proper circumstances, sodium and potassium nitrates.
2. Whole milk and gelatin.
3. Water-dispersible dye.
4. Inorganic salts other than sodium silicate.
5. Coffee extract.
6. Corn syrup.

Arranged according to particle stability or strength, the materials grouped themselves as follows:

1. Friable materials. These include salts other than sodium silicate, and Marasperse-C.
2. Particles collapsing without fracture. These include sodium silicate, milk, and gelatin.
3. Particles resisting deformation. These are coffee extract and corn syrup.

These groupings are not sharp and specific, and product characteristics might be varied by special operating conditions; however, the groupings indicate what can be expected in the way of product properties when similar materials are spray dried.

From these considerations, three classes of materials were proposed to predict product properties. The first class includes those materials that exhibit marked film-forming tendencies, which on drying form large hollow particles, and the bulk density of which would be relatively sensitive to temperature. The second class is made up of crystalline materials that form particles generally spherical and hollow but of smaller size than those of the first class and with high friability. The third class includes materials intermediate between the first two, i.e., materials with limited film-forming tendencies whose dried particles strongly resist fracture and breakage.

Sodium and potassium nitrates revealed an unexpected tendency to form large, hollow, balloonlike particles under certain drying conditions. Typical spheres of this type had diameters of 1800 to 2000μ with wall thicknesses of 5 to 20μ. Figure 18 shows potassium nitrate particles of this nature. By means of supplementary experiments in which a stream of drops of potassium nitrate solution were bounced off a hot plate and into a hot-air stream such particles could be formed. This indicated that residence time of the drop in the high-temperature zone of drying or impingement on a hot surface may have been important in the formation of these particles. Since the drops from which these particles were formed were of the order of 20% of the diameter of the resulting particles, the experiments rather strikingly demonstrated the mechanism of hollow-particle formation by vaporization within an elastic shell, causing puffing or "ballooning" of the particle.

TABLE 5.—PROPERTIES OF DRIED PRODUCTS

Material Figure number Operating conditions	a. Nature of product particles. b. Remarks.
NH_4NO_3 $t_1 = 395°$ C. $t_2 = 140$ $t_f = 43$ $C_f = 60\%$	a. Particles were nearly spherical with small dimples evident on many; crystalline aggregates, hollowness not obvious, particles fractured with some difficulty.
Na_2SO_4 Figure 17 $t_1 = 315°$ C. $t_2 = 152$ $t_f = 57$ $C_f = 25\%$	a. Particles were hollow, crystalline, and most of them showed holes with edges rounded inward, as if imploded or blown inward. They shattered easily, were thin walled with radius/thickness ratios of the order of 10. b. Low original bulk density but high friability would result in degradation and dusting.
KNO_3 Figure 18 $t_1 = 340°$ C. $t_2 = 148$ $t_f = 30$ $C_f = 31\%$	a. Two types of particles were observed: 1) roughly spherical crystalline aggregates similar to other salts, easily crushed, and 2) large, balloonlike thin-walled spheres, diameters 1800 to 2000 μ, wall thicknesses 5 to 20 μ, highly soluble, apparently noncrystalline in structure, which tear or fold without shattering. b. See discussion in text.
Dye AQD 585A† Figure 10 $t_1 = 415°$ C. $t_2 = 133$ $t_f = 75$ $C_f = 19.5\%$	a. Particles were generally spherical, hollow, apparently homogeneous, and noncrystalline in nature. They shattered into shell-like fragments on application of moderate pressure. b. An attractive, stable product with little dusting tendency. † These are data typical of those obtained in the experiments described in detail in the text.
Corn Syrup Figure 19 $t_1 = 415°$ C. $t_2 = 132$ $t_f = 65$ $C_f = 35\%$	a. Particles were clear solid spheres with no evidence of hollowness. They fractured only with great difficulty. b. A high-density, stable product. The material may have melted or softened during the later stages of drying.
Whole milk Figure 20 $t_1 = 400°$ C. $t_2 = 120$ $t_f = 130$ $C_f = 26\%$	a. Particles were roughly spherical, thin walled, and hollow and split or folded without other fracture on application of light pressure. b. Some of the particles degraded at the high temperatures of these experiments.
Gelatin Figure 21 $t_1 = 397°$ C. $t_2 = 125$ $t_f = 115$ $C_f = 4\%$	a. Product consisted of collapsed spheres having a "dried-prune" appearance. They were thin walled (5 to 10 μ) and collapsed without fracture under moderate pressure. b. Low-density, nondusting, stable product. Only the smaller drops could be dried completely in the tower.
$NaNO_3$ $t_1 = 415°$ C. $t_2 = 110$ $t_f = 120$ $C_f = 30\%$	a. Particles were granular cryystalline aggregates and a few large balloonlike spheres similar to KNO_3 (Figure 18). The crystalline product crushed easily under light pressure. b. A dusty, high-density product after size reduction.
Na_2SiO_3 Figure 22 $t_1 = 490°$ C. $t_2 = 203$ $t_f = 62$ $C_f = 25\%$	a. Product consisted of thin-walled, generally spherical particles, apparently amorphous, some balloonlike in nature. Particles folded or split open on application of pressure, without fragmentation. b. Low-density product of a markedly film-forming material. Details of these experiments are described in the text.
K_2SO_4 Figure 23 $t_1 = 505°$ C. $t_2 = 190$ $t_f = 65$ $C_f = 10\%$	a. Particles were hollow, thin-walled spheres, crystalline aggregates, each with a hole in it. They shattered easily under light pressure. b. Typical inorganic crystalline product—dusty, medium-density product after reduction.

NaCl

Figure 24

t_1 = 545° C.
t_2 = 210
t_f = 100 (approx.)
C_f = 19%

a. Particles were hollow, thin-walled spheres, crystalline aggregates, with openings in the particle wall. Application of moderate pressure reduced particles to smaller shell-like pieces.

b. A relatively stable, low-density product. See text for detailed discussion of these experiments.

Marasperse-C

Figure 25

t_1 = 495-445° C.
t_2 = 210
t_f = 80
C_f = 36%

a. Particles were large, roughly spherical, with varying wall thickness. Moderate pressure reduced the particles of this amorphous material to smaller shell-like particles.

b. A relatively stable, low-density product. The material showed strong film-forming tendencies.

The photomicrographs of dried particles of potassium sulfate, sodium chloride, and sodium sulfate show holes with the edges rounded inward. This phenomenon suggests another mechanism in the formation of hollow particles as follows: A relatively stable shell of crystalline material forms early in the drying process on the outside of the drop. The solution in the center of the drop moves to the surface by capillary action, causing a reduced pressure due to capillary suction within the drop and a resulting rupture of the surface inward, or an implosion. Thus, a hollow particle is formed, but the interior pressure is less than atmospheric, and any blow hole is inward, the reverse of the hollow-sphere mechanism that is due to film formation.

From these observations it is possible to postulate three different factors contributing to the formation of hollow particles:

1. Formation of hollow particles due to the formation of films causing puffing or ballooning of the particle.
2. Formation of hollow particles due to the rate of evaporation exceeding the diffusion rate of salts back into the particle, thereby creating internal voids after dryness is reached.
3. Formation of hollow particles due to the capillary action of the material on the drop surface drawing liquid and solids to the surface and creating subatmospheric pressures within the particle.

The combined effect of these mechanisms is that virtually every material that is spray dried consists of hollow spherical-shaped particles. A fourth factor contributing to hollow particle formation is the presence of entrained air in the liquid feed.

Conclusions

In all cases studied and reported in the literature, the bulk density of spray-dried materials was found to decrease with an increase in drying-air temperature. The effect is ascribed to an increased tendency of the particles to expand on drying and to earlier formation of vapor-impervious films on the drop surface.

Increasing the feed temperature may cause an increase or a decrease in the bulk density, the effect being small in either case. Increased feed temperature causes a slightly increased drying rate and influences the particle size from atomization due to viscosity lowering.

The effect of solids concentration may produce an increase or decrease in bulk density, depending largely on whether the increased feed concentration affects the tendency of the particles to expand.

On the basis of observations of dried-particle characteristics, materials dried in this study grouped themselves in three classes:

1. Film-forming materials such as sodium silicate.
2. Crystalline materials such as most inorganic salts.
3. Intermediate materials having limited film-forming tendencies, such as a water-dispersible organic dyestuff. In every instance, these products formed hollow particles, although the mechanism for this hollow formation differed.

Acknowledgments

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Notation

C_f = solids concentration of feed, weight %
D_0 = geometric mean drop diameter, μ
D_j = jet diameter
D_N = nozzle diameter
D_p = drop diameter
d_v = volumetric mean dried-particle diameter
F = feed rate, cc./min.
g = gravitational constant
h = film-heat-transfer coefficient on surface of drop
k_f = thermal conductivity of film
N_{Pr} = Prandtl number
N_{Re} = Reynolds number
t_a = air temperature, ° C.
T_a = air temperature, ° K.
t_f = feed temperature, ° C.
t_1 = inlet-drying-air temperature, ° C.
t_2 = exit-drying-air temperature, ° C.
Δt = driving force for heat transfer
v_t = terminal velocity of drop
w = moisture content, weight %, wet basis
W = moisture content, dry basis, weight fraction
β = a parameter [Equation (7)]
λ = wave length of the disturbance on a jet; also latent heat of evaporation
μ = liquid viscosity; also symbol for micron
ρ_L = density of liquid drops
ρ_p = density of dry particle
ρ_a = density of air
ρ_{B1} = bulk density as measured before settling, g./cc.
ρ_{B2} = bulk density as measured after settling, g./cc.
ρ_{BD} = bulk density corrected to zero moisture content, g./cc.
θ = time

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The End

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Replaceable Micronic Filters
A New Tool for the Chemical Engineer

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Recent studies of filtration, such as Brownell's (*5*) and Grace's (*7*), have in the main dealt with what chemical engineers term the conventional types of filters and filtration processes, such as pressure leaf, rotary vacuum, plate and frame and continuous pressure or vacuum. The number and content of these papers reveal increasing interest in filtration and in progress made towards the eventual goal (*9, 2*) that of predicting the time required or establishing the rate necessary, to effect a given separation. This paper purposes to shed some light on a relatively new member of the filtration family, the cartridge type of disposable filter element.

A survey of leading chemical engineering texts (*3, 4, 10, 11*) discloses the fact that little or no attention is devoted to replaceable, or "throw-away," filter elements or clarifiers, which operate well into the micronic range of particle sizes. The use of these micronic elements is dictated by one or sometimes two desired ends, namely to clarify a fluid, the solids being discarded, or to protect moving machinery through which fluid must pass.

Filter Media

The selection of a filter medium generally is governed by three considerations:

1. The solid particulate matter: its condition, concentration, and particle-size distribution.
2. The carrying fluid: its chemical composition, physical characteristics, line pressure or vacuum, and temperature.
3. Consideration of economy: an evaluation of costs of alternate methods of separation.

There is a maximum concentration limit imposed on filter media. Generally, they are designed to operate on fluids with solid-matter concentration of about 2% by volume or less. This point is one of practical economics, for at any higher concentrations the cartridge life would be so short that the cost of replacements would become prohibitive. The mean particle size of the contaminant solid or its distribution curve, if known, will dictate the degree of retention required of the filter medium. Above the range of 75 to 100μ, there are commercially available strainers (screens or continuously cleaning media) whose operating costs are generally less than those of the replaceable filter elements; below this size and down to the order of ½ to 1μ, these filter elements are economically operable with certain solids. The chemical properties of the carrying fluid, and its physical condition, must be given the same consideration in the design of any item of process equipment.

The capital cost and subsequent operating costs of these filters are a function of engineering judgment in the design specification. It is not possible yet to predict mathematically the required number of filter cartridges necessary for a given job, or to predict their useful service life before replacement is necessary. It is at this point that the particular manufacturers must either rely on their previous field experiences or run sample tests on the customer's fluid in their laboratories to estimate the life of the unit.

Filter Size

The following sequence is representative of how a particular size of unit is determined for a given field application. For example, the customer has already ascertained that he can use a replaceable filter element, concentration is below the upper limit of 2% by volume, and there is no problem chemically or physically. He has further discovered that the particles he desires to remove are in a range of from 25 to 35μ. He also has available about 10 lb./sq.in. of head to handle a flow of 10 gal./min. At this stage of design the manufacturer is invited to make a recommendation and to estimate the capital and operating costs of his recommended unit.

The manufacturer first must determine how many elements are necessary by determining the flow-versus-pressure-drop characteristics of the carrying fluid through his filter elements. He might find, for example, in his laboratory run, that at 10 lb./sq.in. he obtains a flow of clean fluid of 5 gal./min. through a single cartridge. To handle 10 gal./min., therefore, a minimum of two filter cartridges is needed. With the minimum established, he must try to estimate how many additional units are required, so that, as the cartridges begin to accumulate solids, with the attending rise in pressure drop, there will be a reasonable filter life to the cartridges. By filter life is meant the length of time a unit may handle fluid prior to reaching a maximum allowable pressure drop, at which time it is replaced. If a two-filter-element unit were recommended, this would handle the clean flow satisfactorily, but, as the dirt began to accumulate in the filter elements, the subsequent rise in pressure differential would soon exceed the 10 lb./sq.in. maximum set by the customer. The number of additional cartridge elements required to allow for this pressure rise varies from application to application. It is sometimes determined by laboratory trial runs on a customer's sample but more often than not, on the basis of experienced sales engineers' evaluation of the job. Where filters are purchased to specifications, usually by the military, the specifications call for a pressure drop at rated flow with the clean fluid, and also specify the pressure drop after a given amount of specified contaminant

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has been accumulated by the filter. Here there is no estimate required; it either has the capacity or it does not.

To return once again to the example, it has already been determined that the customer would require a minimum of two cartridges to handle his clean fluid. Based on sales engineering estimates, the recommendation would be a twenty-cartridge filter for the particular application. This conclusion was arrived at after comparing this application to a similar application on file with the same solids at approximately the same concentration. For the customer's service, it was estimated that it would be necessary for him to change his filter elements about every 2 weeks. If no prior data were on file, then a laboratory run on the contaminated fluid would be conducted to determine the pressure rise as a function of gallons throughput, at various flow rates per cartridge. From this curve, it might be found that at 0.5 gal./min./cartridge, a total of approximately 2,500 gal. would cause a pressure differential of 10 lb./sq.in. At this flow rate per cartridge twenty elements are required to handle 10 gal./min. with 2,500 gal./cartridge. The total anticipated throughput equals 50,000 gal., or about 83 operating hours. Actually, more than a 10-gal. sample is rarely obtained from a customer, and tests are run on a small section of an element and the results plotted on log-log paper and extrapolated.

This solution represents an optimum condition. If a forty-filter-element unit were recommended, the filter life would be longer but the initial cost considerably larger; conversely, a ten-element unit would have a lower initial cost but a subsequently higher replacement cost.

Cost

It is now possible to figure this customer's operating costs. They are simply the sum of his replacement cartridge costs per unit of time plus his depreciation charges per unit of time divided by the total flow handled in this unit of time.

The points, therefore, that bear directly on either the capital cost or operating cost of these throw-away types of filters are

FLOW RATE: the lower the flow rate the lower the initial cost and the less the replacement cost. In those applications where the system is closed and recirculating, where it is desired to protect moving machinery parts, the total flow is not generally required to be filtered; anywhere from 10 to 50% is generally sufficient. These applications are almost always recirculating lubrication systems, i.e., Diesel lubricating oil systems, centralized coolant systems on machine tools, and paint-applying systems wherein the main reservoir is kept under pump agitation.

PARTICLE-SIZE REMOVAL: In those applications just described, the larger the diameter of those particles which can be tolerated, the coarser the filtration required, with a subsequent lower pressure drop for the given flow rate. With coarser filtration, fewer elements can handle the required flows, and therefore a smaller unit may be used. In process applications, proper determination of the particle-size distribution will allow the engineer to specify the proper density element and thus to eliminate the error of employing too fine an element and causing an unnecessarily excessive pressure drop.

LOCATION IN SYSTEM: if the unit can be located in the system where the line pressure is at a maximum, then at a given flow rate a somewhat longer cartridge life can be obtained. It should be noted, however, that a plot of gram-life of an element versus hours of life, under conditions of constant contaminant concentration entering the cartridge, is an exponential curve. In the case cited above, for example, once the differential pressure has risen to near the 20 lb./sq.in. recommended maximum, a 5% increase in contaminant in the filter will cause about a 25% increase in differential pressure. In terms of increased hours, however, the increase in life will be a function of the contaminant concentration in the system. If there are temperature fluctuations in the system, the point of highest temperature compatible with the physical limitations of the filter unit will yield a lower pressure drop because of the reduced viscosity at the higher temperature.

The proper handling of these design variables can appreciably lower the first cost of these units and maintain their operating costs at a minimum.

Operation

These replaceable filter elements are available to industry in a variety of sizes and types and are composed of fibers, fabrics, paper, porous ceramics, porous plastics, powdered metals, and electroformed screens. All these types operate under three general mechanisms, namely, separation in depth, surface impingement, and chemical adsorption.

The mechanism of separation in depth is employed in those filter media which arrest the solid particles because of decreasing flow-channel diameters. They resemble a tapered tube bent into a corkscrew that stops a marble as it rolls through. Filters operating by this mechanism are dependent on the filter-element volume for capacity and on average fiber diameter and length for degree of particle-size removal (*8*).

Surface-impingement filters operate by arresting the particles on their exposed surface. The two most common examples of this type of mechanism are laboratory filter paper and common screens or sieves. These filters rely on their exposed outer surface for capacity and on average fiber diameter in the former and mesh size or diameter of openings in the latter case for degree of particle removal.

The last mechanism, that of chemical adsorption, rarely operates by itself. These filters are composed generally of fuller's earth or other similarly activated media. Some of the fibrous media employed in the surface-impingement type remove colloidal particles attracted to their fiber surfaces by the secondary bonding forces described by van der Waals. The activated particles, like those of alumina, etc., behave as a depth-type filter because of their physical size and mechanical arrangement.

In attempting to isolate these three types of mechanisms, it is difficult to point to many elements and state categorically that they operate by one mechanism or another. Chemical adsorption is a function of the chemical activity of the media in relation to the solute particles and the carrying fluid; whereas the depth types and the surface-impingement types are functions of the fabrication and use of the media.

DEPTH-TYPE FILTERS

The depth-type filters, which are designed to filter inside the media, are of two basic types, either random packed or oriented in depth.

The waste-packed-element type, an example of the former class, is intended for use in automotive lubricating-oil systems. In general, these filters suffer the handicap of channeling, or internal by-passing, which in their intended service is not serious for the lubricating oil is continuously by-passed outside the filter housing during engine operation. Data about the elements are available only in relation to their lubricating-oil-sludge-filtration characteristics.

The second class of depth-type filters is termed oriented or graded density filters. A filter commercially available in this category is constructed of a yarn wound helically around a central supporting screen, the direction of the windings being reversed for each layer. The external surface has an imposed diamond-shaped pattern, as does each successive layer of crossed yarns. As the yarn is wound, it is napped, the filtration occurring through the napped fibers in these parallelograms and not through the yarn itself, as may be supposed. The material most commonly employed in these filters is a virgin cotton.

Also in this class is the Cuno Micro-Klean filter element, a resin-impregnated woolen fibrous mass, which is described as follows.

Wool of a grade from 64 to 80 (roughly 20 to 25μ) is mixed with various amounts of either smaller or larger diameter cellulose fibers, depending on the ultimate particle-size retention rating of the unit manufactured. It should be noted that the original development work did not overlook other fibers, but wool was the only fiber available at that time that was suitable

for felting, which allowed a workable thickness to be obtained. The fact that adjacent fibers do not lie in complete contact and seal off the vacuum helps to explain the thickness. These fibers are accreted on a brass mandrel from a liquid medium under vacuum. The maximum thickness of the batt so formed is a function of fiber crimp, fiber bending strength, and vacuum.

The first fractional thickness has upon it the full vacuum; the next increment has a lesser amount, as a result of the pressure-drop rise of the fluid in passing through the first section. Ultimately a thickness is reached where the available vacuum is insufficient to hold the wool onto the outer edges of the batt when it is removed from the felting station.

The thickness of the batt is a function of fiber crimp level, fiber stiffness, felting temperature, wool consistency, fiber diameter, and water pH. The fiber diameter and length control the mean minimum particle-size retention.

When the consistency is lowered, the vacuum is maintained for a longer period of time, and thus mechanically the packing of the felted fibers is increased.

The batts are impregnated with a phenolic- or modified phenolic-type resin. To complete the cure, which is limited by the charring temperature of the wool, the cartridges are placed in an oven at 280° to 285° F. (*1*).

To make the various density filters rated as 10-, 25-, or 50-μ particle-size retention elements, the "furnish" is altered. Thus, by increasing the amount of cellulose fibers of approximately 10μ diameter, the mean minimum size of the contaminant particles retained in the filter is reduced; by including a larger amount of a coarser fiber, the mean minimum size of the dirt particles retained in the filter is increased.

In these graded density Micro-Klean cartridges just described, the external surface of the filter has macropores that open into winding, curvaceous, ever-decreasing diameter channels (see Fig. 1). A particle of dirt entering such a cartridge will therefore penetrate to a depth at which it is physically impossible for the particle to continue, because the diameter of the particle is greater than that of the section immediately ahead of it. A second smaller particle will enter the cartridge, proceed randomly into the filter, and perchance may enter the channel just behind the first lodged particles. The pressure will force it to move into an intersecting channel, and it will move along this newer channel until a section is reached that will cause this dirt particle to lodge. This particle is also stopped because of the decreased diameter of the flow path imposed by the closer packing of the woolen fibers as the inside diameter is approached. Particles smaller than the rating of the element are also removed by this filter, because of inertial deposition. As the fluid flows around the fibers, the solid particles are thrown off by centrifugal force into pockets or recesses inside the filter (see Fig. 2).

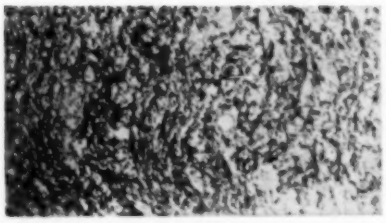

Fig. 1. Cross-sectional photomicrograph of Cuno Micro-Klean showing increase in fiber density from outside to inside surfaces. Flow from right to left.

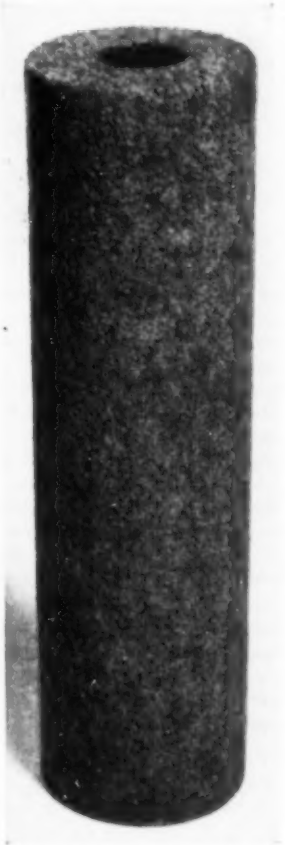

Fig. 2. A Cuno Micro-Klean depth type filter cartridge. Flow is from the outside to the inside.

SURFACE-IMPINGEMENT FILTERS

The most common examples of the surface-impingement type of filter elements are paper or resin-treated paper. These filters were originally designed for automotive use. They operate very much like ordinary filter paper in that once a particle of contaminant has lodged on the surface, the useful life of that portion of the filter has ended. To provide economic length of service, the manufacturers pleat or stack a number of paper disks or spiral wind the paper to form a tube, the thickness of which is equal to the width of the ribbon being wound. Generally, these paper-type filters filter down to a range of from 1μ to 5μ, the range being a function of paper quality and uniformity.

A new development in this field is the electroformed screen. It operates as paper does except that the smallest particle-retention size, as far as the author knows, is about 40μ. Electroformed screens have the advantage, however, of being cleanable and reusable. They are included here because they are similar in function to the throw-away types.

CHEMICAL-ADSORPTION FILTERS

The last general group of filters is the chemical-adsorption type. In this type the filter medium is some activated material like alumina, fullers' earth, or the like. These media by their physical shape will filter particles also. They are used primarily in those applications where the fluid must be kept chemically clean, for example, in transformer cooling-oil systems. They have been used in some systems in which it was necessary to remove colloidal contaminants. In such systems, however, there is the risk that a particle of the medium might migrate into the filter-effluent stream.

Other Filters

In addition to the examples of filters described above, there are still others, which are difficult to define by class. There are available filter elements of powdered metals, porous ceramics, and porous plastics that operate for the most part as surface-type filters but do remove some particles in depth. They have the additional feature of being washable by reverse flushing. Since the backwashing is not 100% effective, they eventually must be discarded, but their useful life is long. Their costs, however, are higher than those of the noncleanable types. When the proper material is used for these "porous solid" filters, there can be no question of chemical resistance.

Filterable Fluids

The operation of replaceable filters and some of the more general types available having been described, consideration will be given to types of fluids to be filtered (*6*). Among specific chemicals are acetic acid (any strength), acetone (50% aqueous), alcohols (methanol through butanol), anhydrous ammonia, benzol, butyl acetate, carbon tetrachloride, cellulose acetate, chloroform, cyclohexane, diethylene slycol, ethyl acetate, ethylene dichloride, ethylene slycol, Freon, hydrochloric acid (10%), some inorganic salt solutions (pH below 10), monocyclic terpenes, monoethanolamine, chlorinated benzenes, perchloroethylene, naphtha, na-

tural gas, oleic acid, petroleum ether, polyvinyl alcohol, styrene monomer, sulfuric acid (12% concentration), vinyl acetate, and vinyl chloride. In addition, there are paints, varnishes, enamels, oils (hydraulic, lubricating and cooling), and fuels (Diesel, gasoline, aircraft, jet aircraft, and guided missile).

These filters are also employed on air used to operate pneumatic recording or recording-controlling instruments. The hydrophobic surface of the woolen-impregnated elements serves to arrest the flow of entrained water (not moisture), in addition to removing solid contaminant particles, either of which would shorten the life of the instrument in question.

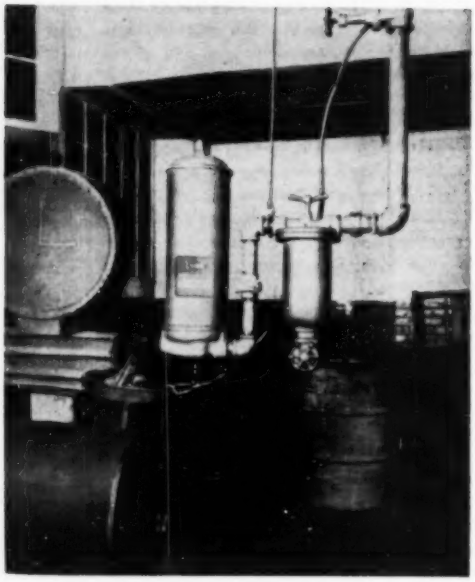

Fig. 3. "In-line" installation of a Micro-Klean filter.

Summary

Increasing interest in micronic throw-away filter cartridges for clarifying fluids or protecting equipment has been noticed in the chemical and petrochemical industries. The engineering data available regarding performance of these cartridges in terms of degree of filtration are growing as new techniques are devised. The data for determining the necessary size of a filter unit have lagged, and manufacturers are necessarily operating empirically at present; improvements are being made however in this direction.

These filters are generally inexpensive to operate when total costs, both fixed and operating, per gallon are considered. The units have the additional advantage of being installed in the piping system, because they escape the space limitation imposed by larger, more conventional equipment (see Fig. 3). They are called "in-line" filters when installed in such an arrangement. These filters are not the final answer to any and all filtration clarifying problems, but they do have a distinct function where it is important to have a clean, clarified fluid in the chemical-process plant at low cost per gallon.

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Discussion

Lawrence B. Trenholme (Carbide and Carbon Chemicals Co., LaMarque, Texas): What would be the maximum capacity that would be economical to put through these throw-away filters? By capacity I mean throughput, say 100 to 300 gal./min.

Edward Kane: We have built housings which will hold as many as 150 of the cartridges shown in Figure 2. On a water-filtration job in a housing holding 90 cartridges of the 50-μ particle-size-retention type, the flow rate was 850 gal./min. In any specific application, however, there are many variables which enter into specifying the maximum throughput. I believe I covered these in the course of the paper.

E. J. Stanley (Commercial Filter Corporation, Cranford, N. J.): Could you tell me, Mr. Kane, what method you use for determining the micronic rating of cartridges?

Kane: To determine the particle-size retention of a particular filter is an involved procedure. We have used American Optical graded dusts, A.C. road dust, and are presently working with glass beads furnished by the Minnesota Mining and Manufacturing Co. These glass beads have been fractionated down to a range of from 10 to 20 μ diam. and are sufficiently sized for 10-μ filters. When we evaluate the 25- or 50-μ filters, we use American Optical graded dust and in conjunction with that the A.C. standard road dust. They are not the best media, but it is all that we have available at the present time.

Stanley: Would you say then that if you had a particle of a different nature from the dust and the glass beads you might get an entirely different result in regard to micronic efficiency of the cartridges?

Kane: That has been the case, as a matter of fact, in some instances. But for the variety of products we filter, it would be next to impossible to set up a standard basis for each industry that we serve. By and large, it has worked out well. There have been isolated cases where there has been no correlation between the particular contaminant found by our customer and our rating or our method of determining the rating in the laboratory.

J. M. Gregory (National Distillers Chemical Co., Ashtabula, Ohio): Mr. Kane, I'd like to hear your comments on the temperature limitations for these filters. We are interested specifically in filtering liquid metals at a temperature of about 110° C.

Kane: At the present time we are limited by the charring temperature of wool, which is approximately 280° F. (dry heat). We have filtered Bunker *C* oil, for example, at temperatures as high as 300° F. Very likely your 110° C. would be satisfactory, although I suggest we try it out first before I commit myself here.

Gregory: What type of element did you use for Bunker *C* oil?

Kane: We used the woolen element that I described in the paper.

Presented at A.I.Ch.E. Forty-fifth annual meeting, Cleveland, Ohio.

Bench-Scale Equipment for Reactions at High Pressure

A. M. Whitehouse, P. L. Golden, R. W. Hiteshue, and E. L. Clark Bureau of Mines, Bruceton, Pennsylvania

Since the publication of an earlier paper on high-pressure equipment (*1*), further investigations involving high pressure have led to the development of other useful equipment. These items, back pressure regulator and low volume pump, for example, were developed to satisfy a requirement probably not met by any commercially available items. Some fittings were devised to suit existing equipment and meet more severe operating conditions. These fittings are far from ideal and the purpose in describing them is to indicate what will work and to give test data that may be of some interest. Assuming familiarity with the subject on the part of the reader, the authors have omitted much pertinent data. However, for detailed descriptions of a variety of fittings, closures, and sealing ring design, such sources as Newitt (*2*) and Tongue (*3*) are available.

High-Pressure Connections

The primary problem in assembling the components of a high-pressure system is the connection of the tubing to the parts. A welded joint is the most direct and permanent form of connection and has the advantage of remaining leakproof over the entire range of pressure and temperature to which the tubing may be subjected. With this method of attachment, tubing can be brought from a point subjected to thermal shock to a zone of essentially constant temperature where a fitting may be inserted which permits the making and breaking of the connection. Alternatively a spring-loaded connector may be used (*1*), but experience at the Bruceton laboratories has led to a preference for the welded connection. Butt-welded joints would be better, but socket welding is usually more practical for small diameter tubing. When tubing must be welded to larger masses of metal, abrupt changes in cross section must be avoided or the weld will almost certainly develop cracks and leak. Figure 1 shows a thermocouple well extending from the inside of the head to the center of the body of an autoclave. A socket for the thermocouple well is made an integral part of the head to provide the necessary transition in thickness of metal. Attempts to seal the tubing by welding to heads not provided with this socket were unsuccessful.

The necessity of occasionally disconnecting the majority of joints in a system demands a device that is easy to apply and is leakproof when used with reasonable skill and care. For pressure less than 5000 lb./sq.in. gauge and for tubing 5/16 in. or less in outside diameter the double-cone cinch is satisfactory. Figure 2-*A* shows this cinch, which was used for many years at the Fixed Nitrogen Research Laboratories. Tightening the cinch nut deforms the cinch against the radius provided in the body of the fitting. This deformation is transmitted to the tubing which is slightly pinched; the tubing is thus held in place, and the seal between the tubing and cinch is completed. This type of connection has some disadvantages compared to commercial fittings in which the seal is made on the coned end of the tubing as shown in Figure 2-*B*. Two opportunities for leakage exist in the double-cone cinch (between cinch and tubing and between cinch and fitting) but only one in the coned tubing connection. The coned tubing fitting has the advantage of being suitable for much higher pressures. Advantages of the double-cone cinch, within its service limitation of 5000 lb./sq.in. gauge, are the ease of preparation since no threading or coning of the tubing is required, permitting the extension of the tubing beyond the fitting for dip tubes or thermocouple wells, and its suitability for use with thinner-walled tubing than that required for the coning operation. Two operations requiring simple tools are essential. The outside diameter of the tubing is cut to a maximum permissible size and the cinch is set on the tubing.

The erection of a pilot plant for use at 7500 lb./sq.in. gauge led to the design of a fitting (Fig. 2-*C*) in which a cinch is threaded on the tubing and sealed to it by silver soldering. The silver soldering is not good for those joints where mercury might be present. Another fitting (Fig. 2-*D*), developed to circumvent the silver soldering, utilizes a metallic gasket to effect a seal between the tubing end and the cinch. This connection is satisfactory for service up to 12,000 lb./sq.in. gauge, provided the

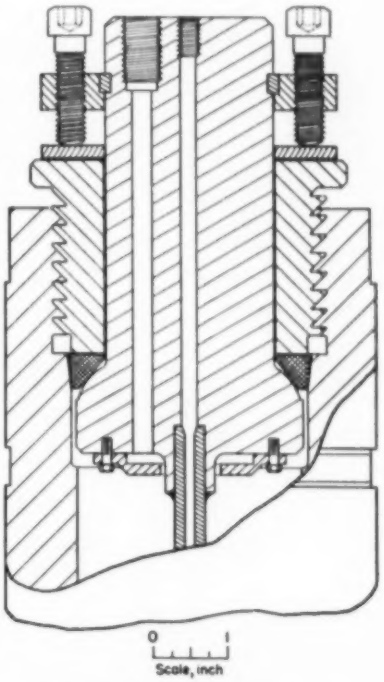

Fig. 1. 5,000 lb./sq.in. gauge autoclave closure.

tubing is not under stress due to misalignment or subject to accidental displacement, which deforms the gasket and causes leakage. There is a chance that the cinch may be tightened too much in making the gasket seal, thus shearing the tubing at the root of the thread. The fitting shown in Figure 2-*E* was devised for the same purpose. The tubing is turned down to the root diameter of a 1/4-40 thread for a short distance and threaded for the cinch. The cinch fits the turned-down portion of the tubing snugly and is thus in position to be sealed against the tube. Though more intricate than the cinch using the metal gasket, it was thought to be superior in that it would be less subject to leakage due to thermal shock or accidental application of force to the tubing. While this may be true, no great difficulties have been encountered with the gasketed cinch (Figure 2-*D*), which is preferred because of its relative simplicity. The screwed cinch (Figure 2-*E*) is used, however, when the tubing must be extended beyond the fitting for a dip tube, standpipe, or thermocouple well. These fittings were devised to fit an existing condition and are described primarily to indicate methods that will work.

To evaluate the mechanical strength of some of these connections, a pull-out test was devised which consists of suspending weights from the tubing to determine the force needed to pull the tubing out of the connection. Results of tests on six specimens of the double-cone type (Fig. 2-A) showed that the force was equivalent to an internal pressure of about 20,000 lb./sq.in. gauge; this value was substantiated by hydrostatic tests. Applying a safety factor of four set 5000 lb./sq.in. gauge as the maximum operating pressure for the double-cone cinch. A specimen of the type illustrated in Figure 2-D was able to sustain almost twice as much force in the pull-out test before the screwed cinch was dislodged.

For further testing of cinch 2-D, five persons each prepared two samples consisting of 15-in. pieces of stainless steel tubing (type 347) ¼-in. O.D. and ⅛-in. I.D. with cinch 2-D installed at both ends. One sample of each pair had copper washers, the other stainless steel washers. Seven of the samples held to a hydrostatic pressure of 50,000 lb./sq.in. gauge; three began to leak between 40,000 and 50,000 lb./sq.in. gauge. All samples showed a measurable increase of the outside diameter of the tubing. In two of the three cases of leakage, the gaskets were copper. This does not of itself prove the stainless steel washer to be superior under these conditions. However, stainless steel is now in general use because of corrosion or erosion of the copper gaskets for which we have no explanation since it occurs in cold service at 700 atm. of hydrogen. The use of stainless steel is mandatory in parts of the system which operate at 950° F. or above.

When cinches slip during hydrostatic tests, tubing and fitting hit the steel barricade with great force, even though the energy stored in the test system is much less than that of even a small, gas-filled reactor. This is one of the reasons for securing all interconnecting high-pressure tubing to walls or structural members.

Some of these fittings were developed before satisfactory commercial fittings were available, which are now used whenever convenient. Such fittings require considerable treatment of the tubing before installation. An ideal connection would make coning or threading unnecessary, yet avoid the possibility of "spitting out" the tubing.

Sealing Ring for Autoclaves

In the previous paper (*1*), an autoclave closure was described in which a Monel metal sealing ring was used. (See Fig. 1.) Monel metal has proved to be subject to embrittlement by sulfur and perhaps from other causes such as high temperature. When frequent replacement of the sealing rings became necessary because of cracks at the exposed edge, stainless steel rings (type 304) were substituted. No galling occurs, even where the rings seal against the body of the autoclave, and the rings may be reconditioned about six times. With care the ring may be used for thirty or

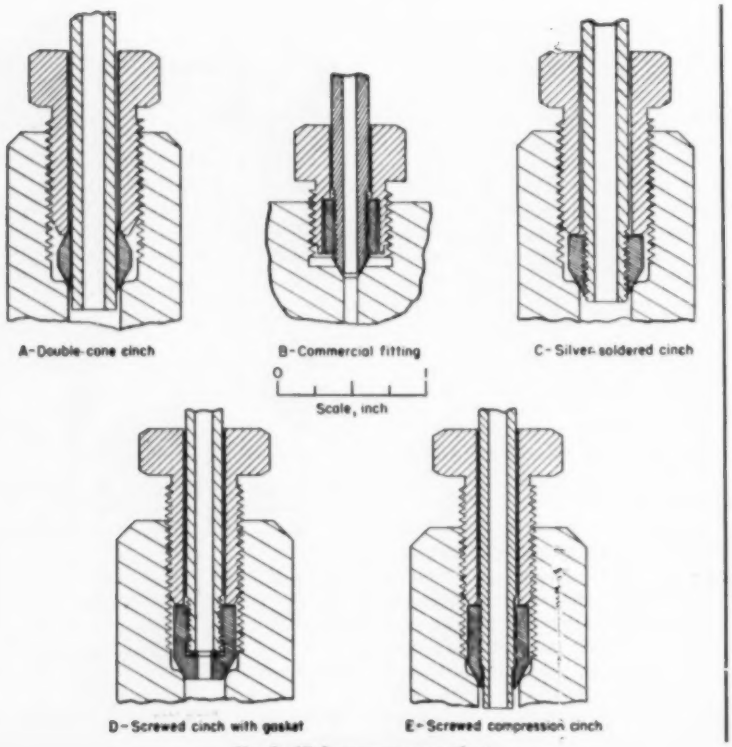

Fig. 2. High-pressure connections.

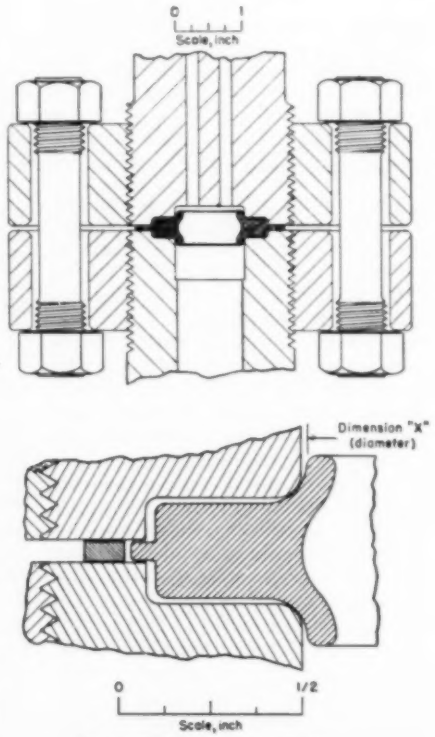

Fig. 3. Sealing ring for autoclaves.

forty seals without reconditioning. Lubrication is important in any assembly of stainless steel parts which are in sliding contact. A mixture of colloidal graphite in oil is available. In some cases where high temperature is involved MoS in water may be effective. The lubricant for any given set of conditions is probably best found by trial and error.

The maintenance required by this type of ring because of its deformation along the narrow band of contact with the vessel head and the possibility of galling or seizing led to the design shown in Figure 3. This ring combines the desirable features of the wave ring and the lens ring and at the same time eliminates some of their disadvantages. The wave ring seals against a cylindrical surface parallel to the vessel wall and since it is proportioned so as to expand radially as the pressure increases, it easily maintains its seal whether the vessel expands or the closure tends to permit the head to move away from the vessel slightly as in the case of a flanged closure.

The lens ring requires the same care in preparation of smooth contact surfaces but no close tolerances are required and assembly is simple.

The ring shown in Figure 3 contacts the head and body sealing surfaces at an angle somewhere between that of the lens ring, about 20°, and the wave ring which seals against the vertical wall of the vessel. This enables the ring to follow the movement of the head as pressure increases more easily than the lens ring. Close tolerances are not necessary. If dimension X is about 0.002 less than the opening into which it fits and the sealing surfaces are polished, the ring will be satisfactory. The indicated radii are not critical since the relationship between the mating concave and convex surfaces is determined at assembly. The clearance between the head and the body is determined with a feeler gauge and a shim in the form of a ring about .004 in. to .006 in. thinner is made and dropped in place to fix the amount of squeeze on the sealing ring. Forming the initial seal requires little force. This reduces initial bolt load below that required by the lens ring and permanent deformation of the sealing surfaces is avoided. The ring was proportioned with the idea that it could be cut and trimmed here and there during a series of pressure tests but an opportunity to use it came along and since it worked well on the first try it was put in service. Type 410 stainless, annealed, was used because the service was noncorrosive and some hesitation was felt over the use of steel identical with the sealing surfaces. Subsequently it was discovered that an 18-8 steel would be satisfactory.

After assembly and a hydrostatic pressure test at 15,000 lb./sq.in. gauge no

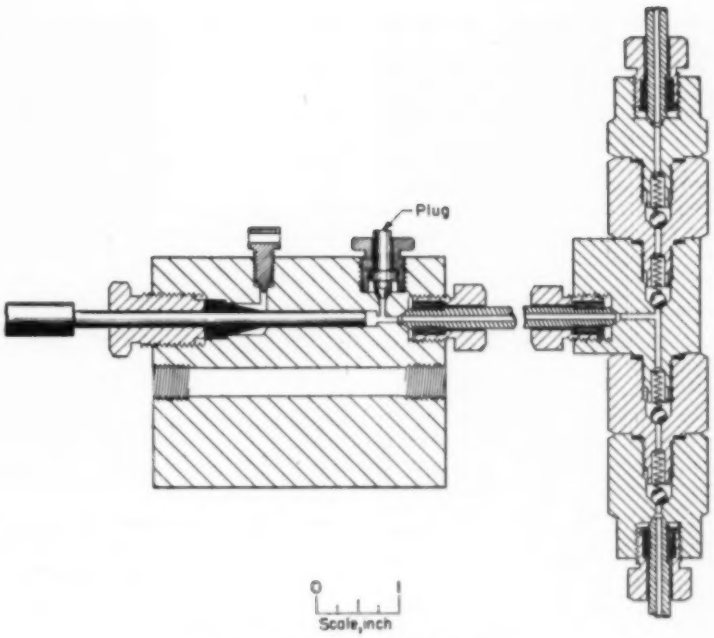

Fig. 4. High-pressure, low-volume pump.

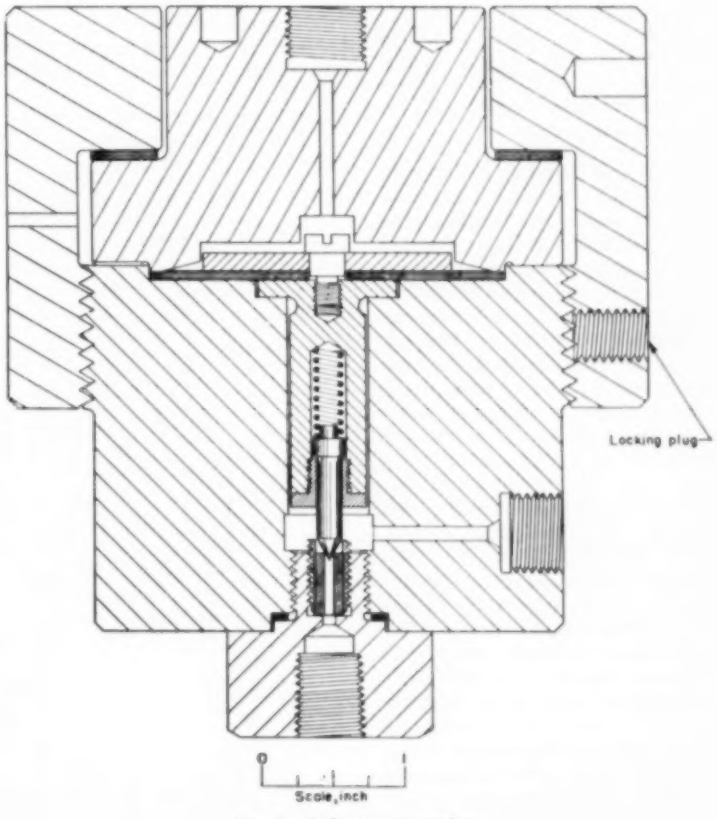

Fig. 5. Back-pressure regulator.

permanent deformation of the contact surfaces could be detected by the unaided eye. This indicates that the vessel can be opened and closed many times without reconditioning the ring or the sealing surfaces. Present use of the ring is at room temperature and 10,000 lb./sq.in. gauge but it would be reasonable to expect it to be satisfactory for use at any temperature and pressure if proper materials were chosen.

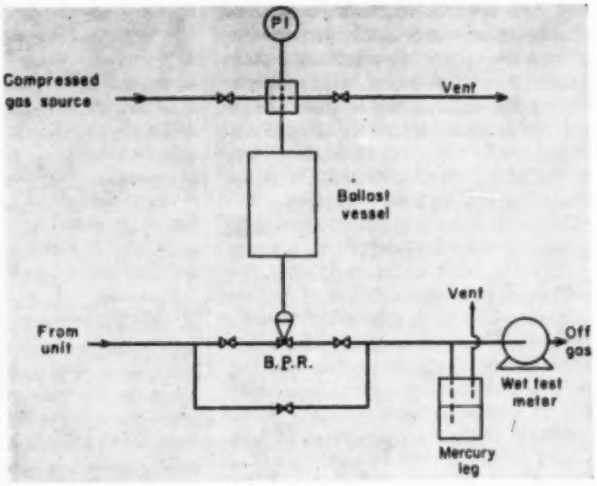

Fig. 6. Flow diagram for back-pressure regulator.

High-Pressure, Low-Volume Pump

The need for obtaining small volumes of liquid at reproducible and constant rates led to development of the pump shown in Figure 4. The hardened and polished plunger, of type 410 stainless steel, is soldered into the crosshead of drill rod which reciprocates in bronze bushings in the crosshead guide. To lengthen the life of the packing the surface of the plunger is made as smooth and uniformly cylindrical as possible. Concentricity and alignment of the parts also contribute to packing life. The plunger is of ⅛-in. diam. and enters the pump body, which is drilled with a No. 30 drill (0.1285 in.). The pump body is of type 303 stainless steel to facilitate machining. The packing is a conical Teflon sleeve which provides a tight fit on the plunger and is forced against it during the forward stroke by the pressure. Double ball valves were used on both suction and discharge. The balls and valve bodies are stainless steel, and the balls are positively seated by phosphor-bronze wire springs. Neoprene gaskets are used between the parts of the valve assembly. The pump body and valves are tapped for commercially available tubing fittings. Structural parts not in contact with the fluid being pumped are of mild carbon steel (C-1018).

This pump has been used to pump oil (SAE 10 lubricating oil) into an accumulator to displace gas at a constant rate of about 215 cc./hr. and at a pressure of 4,000 lb./sq.in. gauge. So far, the pump has had about 200 hours service in a series of 8-hr. runs in a bench-scale unit. No maintenance of any kind has been required in this service, and the rate varies less than 0.1 cc./min., as determined by checking the volume delivered in a few minutes from a burette graduated in tenths of a cubic centimeter.

An identical pump was used for pumping 30 to 50 cc./hr. of solutions of which methyl or ethyl alcohols were the solvents. Some trouble was caused by the combination of poor lubricating properties and occasional deposition of precipitated particles in the check valves. Occasionally, an 8-hr. run was made without tightening the packing nut or cleaning a check valve; but at worst the packing needed two adjustments during a run, and the check valves occasionally required cleaning. With alcohol alone, occasional packing adjustment was the only maintenance required. As shown by the trouble with precipitated particles, this pump is not suitable for slurries.

Back-Pressure Regulator

Pressure regulation becomes a major problem in systems where total volume is measured in cubic inches, flow rate in fractions of a cubic foot per hour, and pressure in hundreds of atmospheres.

No commercially obtainable back-pressure regulator appeared to be suitable for such service. Consequently, the regulator illustrated in Figure 5 was designed. It is built of type 303 stainless steel except for the cap of cold-rolled steel, the hardened type 410 pressure ring and needle, the seat insert of Teflon, the neoprene diaphragm, and the music wire spring with the purpose of permitting the stem to follow any deformation of the soft seat and of preventing excessive loading of the seat.

Gas in a ballast vessel connected to the space above the diaphragm is compressed to the pressure at which the unit is to operate. This pressure acting on the diaphragm forces the valve into the valve seat. This prevents escape of gas from the unit until the pressure in the unit approaches that of the ballast vessel. At this point the diaphragm is balanced. Slight excess pressure in the

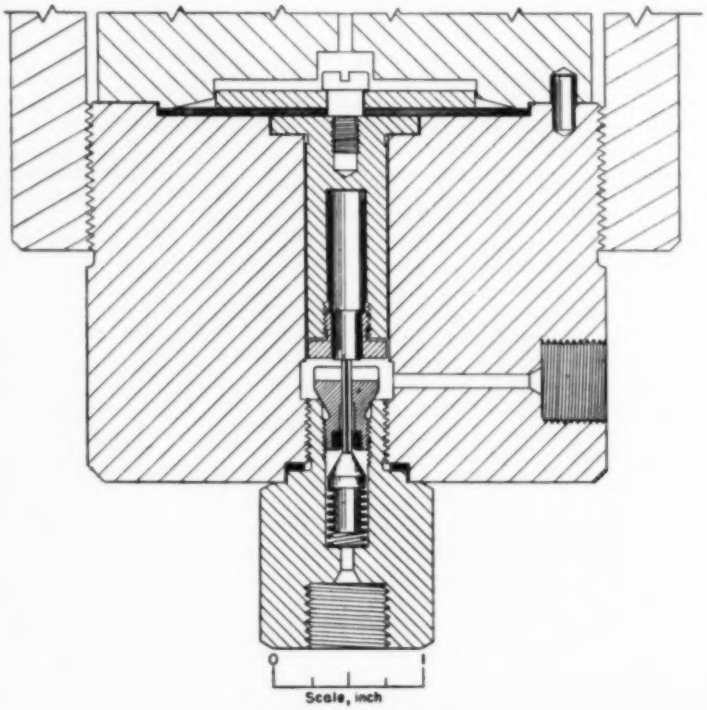

Fig. 7. Pressure regulator.

unit from the side connection lifts the valve stem from the seat and gas escapes from the unit through the bottom connection. This reverses the action of the regulator and the valve closes. No trouble was experienced after it was found initially that the clearance of the parts which retain the diaphragm must be of the order of 0.0015 to 0.005 in. to prevent extrusion of the neoprene diaphragm. Of course, trouble other than that due to the construction of the regulator, can be caused by the deposition of solid material where it interferes with proper alignment of the stem and seat (Fig. 6).

This device has maintained a system at a pressure of 4000 lb./sq.in. gauge for twenty-five 8-hr. runs at a flow rate of approximately 2 cu.ft./hr. (S.T.P.) or about 215 cc./hr. at 4000 lb./sq.in. gauge. It has also operated continuously in three operations of two-months' duration. Controlled pressure ranged from 300 to 1500 lb./sq.in. gauge and flow rates from 0.3 to 2 cu.ft./hr. (S.T.P.).

Figure 7 shows a modification of this regulator to afford pressure control. It uses the same case as the back-pressure regulator but reverse acting internal parts. The inlet pressure may range from full bottle pressure (2,000 lb./sq. in. gauge) to near the process pressure as the bottles are emptied. It has been in service for approximately 2½ months (24 hr./day), two months at 1000 lb./sq.in. gauge and two weeks at 500 lb./sq.in. gauge. Even at flow rates of 2 cu.ft./hr. (S.T.P.) it has given no trouble from leakage, chattering, or other causes.

As is the case with all gas-loaded and sealed instruments, the back pressure regulator and the pressure regulator act as gas thermometers, their balance points vary with changes in dome pressure caused by temperature fluctuations. Choice of a suitable location for the ballast vessel eliminates this trouble.

One unit has been equipped with both a back pressure regulator and a pressure regulator. The back pressure regulator maintains the pressure of the unit and the pressure regulator reduces and regulates the gradually decreasing bottle pressure to a value about 50 lb./sq.in. gauge greater than the process pressure, permitting throttling of flow rates from an unvarying pressure source.

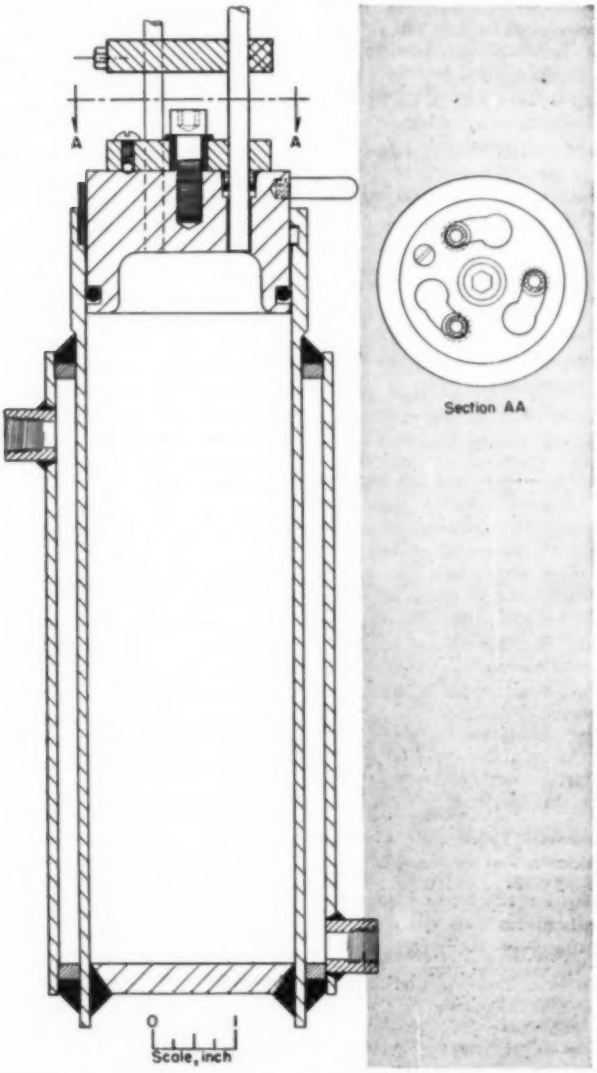

Fig. 8. Quick-opening product receiver.

Quick-Opening Product Receiver

In several of the units at Bruceton, material is periodically emptied from the product separators (at operating pressure) into product receivers (normally at atmospheric pressure). These receivers must be connected to an exit-gas meter and usually also to a source of nitrogen or other inert gas. Since the unit may be operating continuously, receivers may be emptied many times in the course of a run, and a quick-opening closure is desirable. As the contents of the unit may be toxic or irritating and as material balances are desired, accidental losses must be avoided and the receiver must be sturdy. The vessel shown in Figure 8 makes use of O-rings to provide a quick-opening closure. It is rated at 500 lb./sq.in. gauge pressure at room temperature and is tested at 750 lb./sq.in. gauge of hydrostatic pressure. It is jacketed for heating or cooling the contents.

The head of the vessel has six lugs which engage six lugs machined into the vessel wall. The head is inserted and turned 30°, thus engaging the projections on the head and in the vessel wall. Just below the projections on the vessel wall, the wall is machined to a taper which compresses the O-ring in the groove on the head, thus sealing the closure. Insertion of a locking block prevents accidental turning of the head to the disengaged position. Three tubes may be inserted in the head, each being sealed with O-rings and held in place with the tube lock which is provided with three keyhole-shaped openings for inserting and locking the tubes. All parts in contact with product and the jacket are of type 304 and 303 stainless steel with the exception of the O-rings. The closure works with ease and certainty.

High-Pressure Flow Meter Assembly

For metering extremely low gas flows, say, 10 to 100 cc./hr. (S.T.P.), at pressures of at least 2000 lb./sq.in. gauge, an orifice is impractical because of the necessarily microscopic diameter and a capillary element would have excessive length. This problem was solved by measuring the pressure drop across restricting disks fabricated of 1/16-in. sintered stainless steel having a pore size of 5μ. (This material is avail-

able in thicknesses up to ¼ in. and pore sizes 5 to 60μ.) These restrictions were silver-brazed to the ends of short lengths (about 4½ in.) of ¼-in. O.D., ⅛-in. I.D. stainless steel tubing. The tubes were fitted into high-pressure tees and installed between pressure gauges. Pressure drops were varied between 50 and 200 lb./sq.in. gauge, and the exit gas (oxygen) was collected in graduated cylinders by water displacement. Tests showed that it was necessary to cover about 70% of the areas of the disks by silver-brazing.

The final element required a 100 lb./sq.in. drop at 2000 lb./sq.in. gauge for an oxygen flow of 10 cc./hr. (S.T.P.). The accuracy of the unit is only about ±15%, but it affords a fair indication of flow rates. Minute solid particles in the gas stream probably cause the large fluctuation. A filter of the same material but having a larger area will therefore be installed up-stream from the element to clean the gas.

Acknowledgment

Thanks are due many members of the staff whose suggestions and information have made possible this appraisal of the equipment and individually J. J. Vidosh and C. R. Siple for the preparation of the illustrations. The quick-opening product receiver was designed by Harold J. Kandiner, now with the Barrett Division, Allied Chemical and Dye Corp., Philadelphia, Pa.

Discussion

Haskell Peddicord (Procter & Gamble, Cincinnati, Ohio: How large a physical setup did you have as far as area is concerned when you started?

A. M. Whitehouse: We have two buildings with a variety of units in both. The area for any one unit would be about 20 × 15.

Haskell Peddicord: Did you take any precautions for the safety of the operating personnel?

A. M. Whitehouse: Yes, indeed. In the case of units operating under pressure there is either a steel barricade provided or in the case of our coal hydrogenation pilot plants we have an 18-in. concrete wall and the unit is isolated completely. The operator is not permitted to enter the stall while the unit is under pressure.

Haskell Peddicord: In the previous paper the author indicated that they built safety into their design and did not provide additional safety equipment. Do you feel that for pilot plant equipment it is necessary to do both—build safety into the design and then provide additional safety barricades?

A. M. Whitehouse: That is general practice. With our rather small bench-scale units the barricade may be just a steel plate erected around the equipment with perhaps screening over the top but I can think of no cases where we do not provide protection.

A. I. Johnson (University of Toronto, Toronto, Ont., Canada): What kind of temperatures are involved in the thermal shock that you mentioned.

A. M. Whitehouse: I would say 950° F. to perhaps 1000° F. Some of the autoclaves operate up to 1100° F.

A. I. Johnson: Does that mean then that there is a lower limit to cooling—is that what you mean by thermal shock?

A. M. Whitehouse: Perhaps I used thermal shock in a rather broad sense there. I have in mind the fact that a temperature on a fitting starts at room temperature, goes up to the operating temperature and drops again to certain points during operation, and when the operation is interrupted, it can then be expected that leakage will occur at those joints which experienced temperature variation. Trouble may be experienced whether or not the temperature changes rapidly.

D. R. Hale (Brush Development Co., Cleveland, Ohio): You spoke of using a flashing of copper as a lubricant. Would you indicate how that is put on, how thick it is, and what good it does?

A. M. Whitehouse: My quotation about the flashing is taken from Newitt's "High Pressure Plant and Fluids at High Pressures," Oxford Press.

D. R. Hale: How large a vessel do you think this wave ring—sealing ring—would be useful for, say 6 in. in diameter?

A. M. Whitehouse: We have not used the wave ring. I mentioned the wave ring chiefly because it contributed to our thinking in regard to the special sealing ring. The wave rings with which Dr. Newitt worked ranged up to 6 in. in diameter. We have had experience with only the one special sealing ring but we see no reason why it could not be used up to larger diameters than those practical for the wave ring.

J. N. Romine: (Phillips Petroleum Co., Bartlesville, Okla.): On the steel plate—you didn't mention any thickness for that protection on that barricade.

A. M. Whitehouse: Three eighths is the minimum thickness that we use.

J. N. Romine I notice some of your vessels had flat heads on them at the bottom. Is that right?

A. M. Whitehouse: Yes, it is a quick-opening closure.

J. N. Romine: That means you have a pretty heavy head on the bottom—is it a 750-lb. vessel?

A. M. Whitehouse: That was the test pressure. The service pressure is set at 500. Actually, of course, the vessel should never really be subjected to anything other than atmospheric pressure. The discharge from the product separators passes through a throttling valve which is intended, at least, to reduce the pressure in that vessel to practically nothing. One of those tubes leads to an exit gas meter.

J. N. Romine: This is not a pressure vessel then.

A. M. Whitehouse: It wasn't designed for that purpose but we felt that some strength should be built in just in case.

A. L. Breen (Du Pont Co., Wilmington, Del.): At what pressure level is it necessary for one to start designing his own equipment? In other words, at what pressure level does the commercially available equipment such as fittings, pressure regulators, and so on become inadequate?

A. M. Whitehouse: I would be inclined to say that there isn't any particular pressure. It isn't so much a matter of pressure. It's a matter of the closeness of the control which your operation requires. I dare say that most commercially available equipment might be tailored if it were suitably arranged. We just haven't been fortunate in finding such equipment. As for the fittings, of course, we're saddled with an old inheritance. We have a lot of equipment which was used back in the beginning of this program, and we frequently have to adapt it to existing pieces of equipment. That's why we play around with the fittings so much—there is nothing wrong with the commercial fittings. The scale of bench equipment is so small compared to the usual commercial sizes that it is the minute flow rates rather than the pressure that forces one to improvise.

C. H. Fox (Pure Oil Co., Crystal Lake, Ill.): Would you comment on the maximum pressure range you found operable in the plunger pump which you discussed?

A. M. Whitehouse: The pump is used at 4000 lb./sq.in. I think, without exaggerating, the pump could go up to 20,000, perhaps 30,000 lb./sq.in. but not as the arrangements showed it. That is, the Teflon packing would have to be restrained more carefully against extrusion and flow.

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LIQUID-LIQUID EXTRACTION AT HIGH FLOW RATES IN A SPRAY TOWER

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A number of extraction studies on continuous, countercurrent spray towers at relatively low flow rates have been reported. Studies have been released of limiting flow where no solute was present and consequently no extraction took place. Speculation has been made on extraction performance at high flow rates but no one has presented a study of experimental work on simultaneous extraction at high flow rates and at limiting flow conditions. The present paper covers results on extraction performance of a spray tower over a wide range of flow rates and studies of limiting flow in the spray tower both with and without extraction taking place.

Appel and Elgin (*1*), Row, Koffolt and Withrow (*13*), and Sherwood, Evans, and Longcor (*15*) investigated both spray and packed towers extensively and in general found that extraction was better in packed towers when compared with spray towers operating at corresponding flow rates of both phases. Johnson and Bliss (*8*), who studied spray towers, pointed out that if the two types of towers were compared with each operating at its optimum flow rates, the spray tower could look more favorable than the packed, since considerably higher throughputs are possible in spray towers than in packed towers. Other workers (*6, 7, 9*) concentrated on a variety of systems in spray towers, but the flow rates investigated were limited to a relatively low range. Laddha and Smith (*10*) studied extraction in both spray and packed towers with a two-component system, analyzed their data in terms of H.T.U.'s, and presented correlations for film H.T.U.'s. Licht and Conway (*11*) and Sherwood, Evans, and Longcor (*15*) studied end effects in single drop spray towers.

Blanding and Elgin (*3*) made the first important contribution in the study of limiting flow. They investigated both spray and packed towers and made important observations as to how both types of towers should be designed for attaining maximum throughputs. Subsequently other workers (*2, 4, 5*) examined limiting flow in packed towers. Johnson and Bliss (*8*) made fragmentary observations on limiting flow in spray towers and Minard and Johnson (*12*) presented an extensive work on limiting flow and holdup in spray towers. These latter workers defined the point of limiting flow differently than Blanding and Elgin did. None of the work on limiting flow was carried out while transfer of a solute from one phase to the other was taking place.

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Calculations

The total rate of solute transfer, N, may be computed from data on either phase:

$$N_K = SL_K(C_{K2} - C_{K1}) \; ; \; N_W = SL_W(C_{W2} - C_{W1}) \qquad (1)$$

where

S = tower cross-sectional area,

L_K and L_W = flow rate of ketone and aqueous phase,

C_K and C_W = solute concentration in the ketone and aqueous phases.

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1 and 2 denote the bottom and the top of the tower.

Obviously N_K and N_W should be equal, but they are written separately so as to provide a means for checking the over-all solute material balance for an experimental run.

The over-all extraction coefficient based on the ketone phase, K_Ka, is calculated by means of the usual log-mean driving force equation:

$$K_Ka = \frac{N}{V(\Delta C)_{LM}} \qquad (2)$$

where

$$(\Delta C)_{LM} = \frac{(C^*_{K2} - C_{K2}) - (C^*_{K1} - C_{K1})}{\ln \dfrac{(C^*_{K2} - C_{K2})}{(C^*_{K1} - C_{K1})}} \qquad (3)$$

C^*_K is the equilibrium concentration of solute in the ketone, a function of C_W. V is the total effective tower volume.

Equation (3) will be applicable as long as a straight line drawn through the points (C_{W1}, C^*_{K1}) and (C_{W2}, C^*_{K2}) on a plot of C^*_K vs. C_W approximates closely the actual equilibrium function. In other words, it is only necessary that the equilibrium line be approximately linear over the range of operation.

If all drops of the dispersed phase are assumed to pass through the tower at the same velocity, it may be shown that the per cent of volumetric dispersed-phase holdup, H_f, is given approximately by

$$H_f = \frac{L_D}{v} \times 100 \qquad (4)$$

where v is the linear velocity of drop movement. Values reported in Table 3 for H_f are not regarded as reliable because measured values of v were not precise, and, furthermore, there is some variation in drop velocity, particularly at high dispersed-phase flow rates.

Materials

One system was studied exclusively, methyl isobutyl ketone-acetic acid-water. This system was selected because its equilibrium relationship is practically linear over the range of interest and because data for comparison are available on extraction work with the same system by other investigators (*3, 8, 11, 14*). Technical grade methyl isobutyl ketone manufactured by Carbide and Carbon Chemicals Co., glacial C.P. acetic acid, and Knoxville city water were used. Both water and ketone samples were analyzed for acetic acid by titration with either 1 N or 0.1 N standard sodium hydroxide solutions with phenolphthalein as indicator. Equilibrium data were obtained at room temperatures varying between 68 and 75° F. and are tabulated in Table 1. The data agree within 2% with those of Scheibel and Karr (*14*) taken at 77° F. Indications are that variations in equilibrium

For complete experimental data for extraction runs order Document No. 3984 from ADI Auxiliary Publications Photoduplication Service, Library of Congress, Washington 25, D. C., remitting $1.25 for microfilm or $1.25 for photoprints.

distribution with temperature over a limited range are slight. All extraction runs were made at room temperatures and in all cases equilibrium data of Table 1 were used in computation of over-all coefficients. A saturated solution of a technical grade of sodium hydroxide was used to neutralize acetic acid contained in the ketone before recovering the ketone by steam distillation.

Apparatus and Procedure

The experimental apparatus is shown diagrammatically in Figure 1 and photographically in Figure 2. In both instances the arrangement shown is that used when the lighter or ketone phase was dispersed. The entire extraction tower (T) was of one piece Pyrex glass construction and comprised a 2-in. I.D. tube 29.47 in. long fitted with flared, enlarged end sections of 6 in. I.D. The entrance section for the dispersed phase was 6 in. long and was connected to the main tower section by means of a conical reducing section. The entrance section for the continuous phase was 6.5 in. long and was fused to the main tower section 1.5 in. from its end. The ends of the tower were closed by means of ¼-in. aluminum plates fastened to the tower end sections by means of aluminum flanges fitted over the flared ends. Steel rings were used to support the aluminum plates to prevent their bending. Asbestos compression gaskets were fitted between the aluminum end plates and the glass tower ends. The tower design was based upon recommendations of Blanding and Elgin (3).

The dispersed-phase distributors (D) were made of stainless steel and consisted of discs 1.9 in. in diam. mounted on conical sections 2 in. long. Two distributors were used; one with 56 holes of 0.101-in. diam. drilled in the disk was used at high dispersed-phase flow rates and the other with twenty-one holes of the same size, at low rates. A distributor was mounted in the lower enlarged section of the tower slightly above the point where the conical portion began. Two exit lines for the continuous phase were provided below the dispersed-phase distributer. Two continuous-phase entrance lines extended into the annular space of the upper enlarged end and a single dispersed-phase exit line was attached flush to the aluminum end plate of this section.

Closed feed tanks (F) of 110-gal. capacity were fabricated of aluminum and provided with Saran tubing sight gauges (S) and pressure relief valves set at 40 lb./sq.in.gauge (not shown in Fig. 1). Feed flow of both phases was motivated by means of air pressure provided from a 100 lb./sq.in. gauge air source. The high pressure air line was connected to the feed tanks through a pressure-reducing valve set at 15 lb./sq.in. gauge. Open receiving tanks of 100-gal. capacity were also fabricated of aluminum. All lines were constructed of ½-in. aluminum tubing and all valves were ½- or ⅜-in. needle valves. Inlet flow rates were controlled manually by means of valves (A), two being mounted in parallel in each entrance line. Flow rates were indicated by Fischer & Porter Flowrators (R). One Flowrator was calibrated with ketone saturated with water and the other with water saturated with ketone. Densities of the calibration fluids were recorded and correction charts were prepared to give flow rates for fluids of different densities. In every run the density of each entrance stream was measured and recorded. The interface level (L) was controlled by means of a pivot arrangement (I) in the exit line of the heavier phase. It was found that at high flow rates some of the heavier phase had to be drawn off through valve (B).

Operation of the tower during the extraction runs consisted of first making up feed solutions of the desired solute concentrations. In order to insure that each feed solvent was saturated with the other, a layer of water was maintained on the bottom of the ketone feed tank and a layer of ketone on top of the fluid in the water feed tank. The tower was next filled with the two feed fluids such that the interface was at the desired level. The continuous-phase flow rate was set and the dispersed-phase flow rate was then brought gradually up to the desired value. Operation was maintained with constant flow rates and interface level for the time required to reach steady state, about six or seven complete changes of continuous phase, at which time samples of both exit streams were taken. After operation had continued under the same conditions for the time corresponding to one more complete change, another set of samples was taken. The time required for the drops to rise between two fixed marks on the tower was also taken by means of a stop watch. Generally, about seven runs could be made from one batch of feed solutions, and all runs of any such series were at a constant continuous-phase flow rate. Temperatures of both exit streams were taken several times during any one series but in general were found to vary by not more than one degree Fahrenheit. Operation with the heavier or aqueous phase dispersed was exactly the same as with the lighter or ketone phase dispersed except that the tower was literally turned upside down.

Acetic acid-free ketone was recovered by means of a 16-gal. batch copper still shown in Figure 3. The acid was first neutralized with a saturated solution of sodium hydroxide and then steam-distilled.

The procedure for making runs for the limiting flow studies was essentially the same as that used in the extraction runs except that no solute was present in either of the feed streams and consequently no exit stream samples had to be

Table 1.—Equilibrium Data for System Methyl Isobutyl Ketone-Acetic Acid-Water *

ACID CONCENTRATION IN WATER LB. MOLES/CU.FT.	ACID CONCENTRATION IN KETONE LB. MOLES/CU.FT.
0.00449	0.00210
.0169	.00816
.0331	.0165
.0496	.0258
.0654	.0352
.0811	.0450

* Temperature fluctuated between 68.8° and 74.8° F.

Table 2.—Summary of Conditions of Different Series

SERIES NUMBER	FLOW RATES FT./HR. L_D	FLOW RATES FT./HR. L_C	PHASE DISPERSED*	DIRECTION OF EXTRACTION†	RUN NUMBERS
1	143–242	45	ketone	ketone to water	1–6
2	128–251	136	ketone	ketone to water	7–12
3	128–290	45	ketone	water to ketone	13–18, 33, 34
4	129–233	136	ketone	water to ketone	19–25
5	85–202	195	ketone	water to ketone	26–32, 35, 36
6	45–128	45	ketone	water to ketone	37–41
7	45–109	135	ketone	water to ketone	42–45
8	45–86	195	ketone	water to ketone	46–48
9	45–142	45	ketone	ketone to water	49–54
10	68–142	45	water	ketone to water	55–59
11	142–288	45	water	ketone to water	60–66
12	129–273	45	water	water to ketone	67–73
13	129	45–195	ketone	water to ketone	13, 19,128
14	153	45–195	ketone	water to ketone	14, 20, 30
15	176	45–195	ketone	water to ketone	15, 21, 31
16	202	45–195	ketone	water to ketone	16, 22, 32
17	45	45–195	ketone	water to ketone	37, 42, 46
18	68	45–195	ketone	water to ketone	38, 43, 47
19	90	45–195	ketone	water to ketone	39, 44, ‡
20	109	45–195	ketone	water to ketone	40, 45, ‡
21	143–230	47–195	ketone	limiting flow studies (no solute)	¶

* In series 6 to 10 and 17 to 20, the distributor with 21 holes was used. In all other series the 56-hole distributor was used.

† In all series with the direction of extraction from water to ketone the average entering solute concentration in the water was .0522 lb.-mole/cu.ft. For all other series the average entering solute concentration in the ketone was 0.0285 lb.-moles/cu.ft.

‡ Third point was obtained by extrapolation of curve for series 8, Fig. 4.

¶ See Table 4.

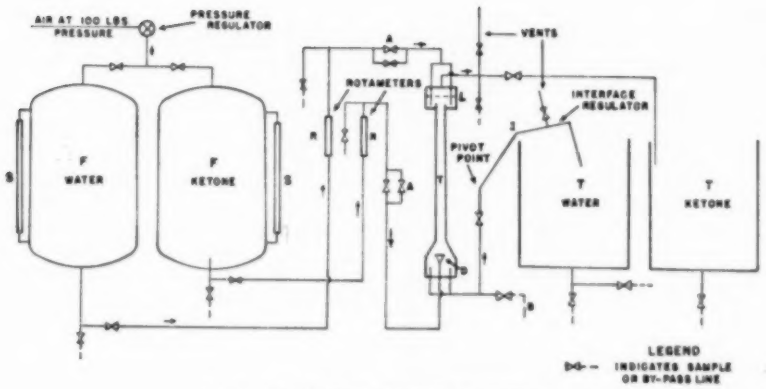

Fig. 1. Flow diagram of extraction apparatus.

taken. Under limiting flow conditions the tower was allowed to operate 15 to 20 min. longer than the usual six or seven changes of the continuous phase.

Results

VARIABLES STUDIED

Flow rates of both phases were varied over wide ranges and all four possible combinations of phase dispersed and direction of extraction were studied. Emphasis was placed upon the case of ketone dispersed and extraction from water to ketone for reasons that will be discussed in a later section. Brief studies were made of flooding conditions where no solute was present. Table 2 summarizes the various series of runs showing flow rates, runs involved, phase dispersed, and direction of extraction of each. The 56-hole distributor was used in runs of high dispersed-phase flow rates, but because some of the holes in this distributor became inoperative at lower dispersed-phase flow rates, the 21-hole distributor was used for all runs of dispersed-phase flow rate lower than 142 ft./hr.

APPEARANCE OF TOWER DURING OPERATION

For the case of ketone dispersed and direction of extraction from water to ketone, absolutely no coalescence was observed and the drops rose smoothly in a straight line as the dispersed-phase flow rate was increased, with the continuous-phase flow rate held constant, up to a certain critical value. At this critical point the condition of no coalescence persisted but the drops began to swirl around in the lower portion of the tower, and this rotating motion was distinct. Furthermore, at this critical point the bottom of the region of high drop holdup fell from a level just below the beginning of the conical end section of the tower to a level about ¾ to 1¼ in. lower. As the dispersed-phase flow rate was increased further the swirling motion became more vigorous and extended further up into the tower, and finally coalescence set in. Eventually, a point was reached where the ketone rose through the tower in large turbulent slugs, and, even under these conditions, no ketone was entrained with the water leaving the bottom of the tower. In fact, the bottom level of the region of high ketone holdup still had not reached the distributor although it continued to assume progressively lower levels after rotary drop movement set in.

The point just described where the swirling motion of the drops first set in was defined as the point of *limiting flow* because as will be seen later this was the point where the maximum overall extraction coefficient was obtained. The spray column behavior described first by Blanding and Elgin (*3*) and later observed by Johnson and Bliss (*8*) could not be detected in the present work. Blanding and Elgin found that a point existed where a sudden transition of the drop holdup in the tower occurred. At this point, which they called *flooding*, a denser region of drops appeared at the top of the tower just below the interface and moved gradually down the tower for the case where the lighter phase was dispersed. Any increase in the dispersed-phase flow rate beyond this point served to lower the level of the bottom of the high drop holdup region from a point at the mouth of the conical tower entrance section to a lower level, and in this respect their flooding point appears to be somewhat similar to the limiting flow point of the present work. Minard and Johnson (*12*) studied limiting flow in spray towers and recommended that the condition where the dispersed phase is rejected with the continuous phase be used as the criterion of limiting flow.

In the present work, limiting flow is taken as the point where a swirling motion of the dispersed phase first sets in, since this condition appears to coincide with that of maximum extraction rate. It is felt, however, that this swirling phenomenon cannot be taken as a

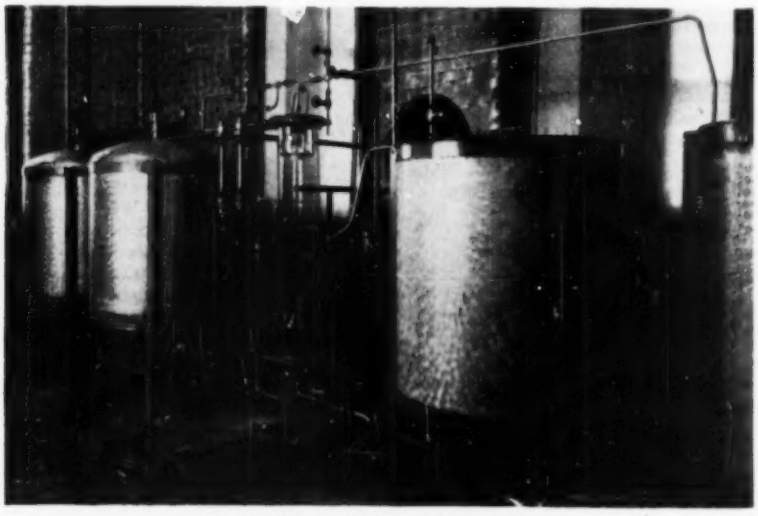

Fig. 2. Photograph of extraction apparatus.

Fig. 3. Photograph of batch distillation unit.

general criterion for maximum extraction rate because visual observations of other workers have been so inconsistent. The phenomenon here may well be caused by characteristics of the particular setup. A more general criterion for maximum extraction rate in a setup employing a conical dispersed-phase entrance might be the condition existing when the region of high dispersed-phase holdup begins to move down into the conical section. Several studies of flooding in packed towers (*2, 4, 5*) have taken limiting flow as the point where the region of dispersed-phase holdup started to move down below the bottom of the packing, and this condition would appear to be somewhat analogous to that recommended here for spray towers.

In limiting flow studies where ketone was dispersed and no solute was used, the behavior in the tower was similar to that just described for the case of extraction from the continuous to the dispersed phase with ketone dispersed. However, coalescence did not occur at any dispersed-phase flow rate above that where swirling set in.

When extraction was from the dispersed to the continuous phase with ketone dispersed, considerable coalescence occurred at all flow rates but was worse at high dispersed-phase flow rates. This observation agreed with that of Johnson and Bliss (*8*). A possible explanation for this coalescence is that as the drops pass through the tower under these conditions the solute concentration in both phases becomes lower and this increases the interfacial tension. As interfacial tension increases, larger drops become more stable and hence tend to form when two or more smaller drops collide.

When water was dispersed it tended to form globules on the flat plate of the distributor and the streams that ran off from these globules broke up into drops of variable size, some quite large. With water dispersed and extraction from the continuous to the dispersed phase no coalescence was discernible after the drops had formed; however, when the direction of extraction was reversed coalescence was pronounced. The explanation proposed here for coalescence with ketone dispersed should apply equally well to the case of water dispersed. Thus it appears that from the standpoint of coalescence it is preferable to disperse the phase that is doing the extraction. As far as uniformity of drop size is concerned, it appears that for the system studied here and the type of distributor used, it is preferable to disperse the ketone. The globule formation at the distributor plate when water was dispersed was probably due to the preferential wetting of the steel distributor plate by the water. Thus it would appear that use of a distributor constructed with a number of individual tips rather than a perforated plate would circumvent this difficulty. Such a distributor was used by Johnson and Bliss (*8*) and they obtained uniform drop size when water was distributed into ketone.

EXTRACTION AND LIMITING FLOW

Sample results for some typical extraction runs are presented in Table 3. Plots of the over-all extraction coefficient vs. dispersed-ketone-phase flow rate are given for various series in Figures 4 and 5.

All plots show the effect of dispersed-phase flow rate, which in general is to increase the over-all coefficient approximately linearly either over the whole range studied or up to a maximum value. The plots for series 3, 4 and 5 in Figure 4 indicate that for the case of extraction from water to ketone with ketone dispersed, a definite maximum value for the over-all coefficient is obtained. These maximum points occur at values of the dispersed-phase flow rates where swirling of the drops in the bottom of the tower was first observed. Thus it would appear that at high flow rates the drops tend to rise through the tower in masses through which there is less effective circulation of the continuous phase than at flow rates just below the point where swirling sets in.

In series 1 and 2, the ketone was still dispersed but extraction was from ketone to water. Under these conditions coalescence was pronounced and became worse with increasing dispersed flow rates; hence, the formation of large drops undoubtedly reduced the over-all coefficients over the whole range and lessened the tendency toward a maximum.

Series 9, 6, 7, 8 comprise runs in which the 21-hole distributor was used and these series may be regarded as extensions of series 1, 3, 4 and 5, respectively. On comparing series 1 and 3, series 6 and 9, or series 2 and 4, the effect of reversing the direction of extraction while keeping ketone dispersed may be seen, and in every case the over-all coefficient is higher for cases where extraction is from the continuous to the dispersed phase. This effect is expected because when extraction is from the dispersed to the continuous phase coalescence occurs and consequently the interfacial area is reduced.

In Figure 5 several series are plotted as over-all coefficient vs. dispersed-phase flow rate, but the coefficients plotted in this figure were obtained with water dispersed in some series and ketone in others. The effect of reversing the phase dispersed is seen on comparing series 9 and 10, series 1 and 11, or series 3 and 12. Over-all coefficients for series 10 and 11 are greater than those for series 9 and 1, respectively. In series 9 and 1 the drops were uniform as they formed at the distributor but coalescence occurred as they rose through the tower; in series 10 and 11 the drops were uneven in size when they formed but no coalescence took place. The coalescence evidently was great enough to reduce the interfacial area sufficiently to lower the over-all coefficients. The over-all coefficients of series 3 were higher than those of series 12. In series 12 the drops were uneven in size as they formed and they coalesced as they rose through the tower, whereas in series 3 the drops were uniform in size as they formed and they did not coalesce on rising through the tower. Thus, again interfacial area would be greater for the case of no coalescence and higher over-all coefficients would be expected. Comparison of series 11 and 12 illustrates again the effect of reversing the direction of extraction.

In Figure 6, series 13 through 20 are plotted and the effect of continuous-phase flow rate on the over-all extraction coefficient is shown. In all cases extraction was from water to ketone with ketone dispersed. The general effect is that the over-all coefficient first increases with the continuous-phase flow rate. Over

Table 3.—Sample Experimental Data for Extraction Runs

RUN NUMBER	CONCENTRATION LB. MOLES/CU.FT. KETONE INLET C_{K1}	KETONE EXIT C_{K2}	WATER INLET C_{W1}	WATER EXIT C_{W2}	FLOW RATE CU.FT./HR.(SQ.FT.) KETONE L_K	WATER L_W	SOLUTE TRANSFER RATE LB. MOLES/HR. KETONE N_K	WATER N_W	AVERAGE N_A	$\left[\frac{N_W - N_K}{N_A}\right]$ %	PHASE DISPERSED	$K_G a$	H_T % HOLDUP
13	0	0.0144	0.0513	0.0115	128.	44.9	0.0402	0.0390	0.0396	3.03	Ketone	75.6	15
14	0	0.0130	0.0513	0.00723	152.	44.9	0.0430	0.0443	0.0437	2.98	Ketone	94.4	21
15	0	0.0114	0.0513	0.00518	174.	44.9	0.0433	0.0453	0.0443	4.52	Ketone	102.	23
49	0.0286	0.0115	0	0.0171	45.0	44.5	0.0167	0.0168	0.0168	0.60	Water	17.4	3
50	0.0286	0.0132	0	0.0237	45.0	67.3	0.0227	0.0233	0.0230	2.61	Water	24.5	4
51	0.0286	0.0142	0	0.0273	45.0	89.5	0.0282	0.0269	0.0275	5.09	Water	29.6	6

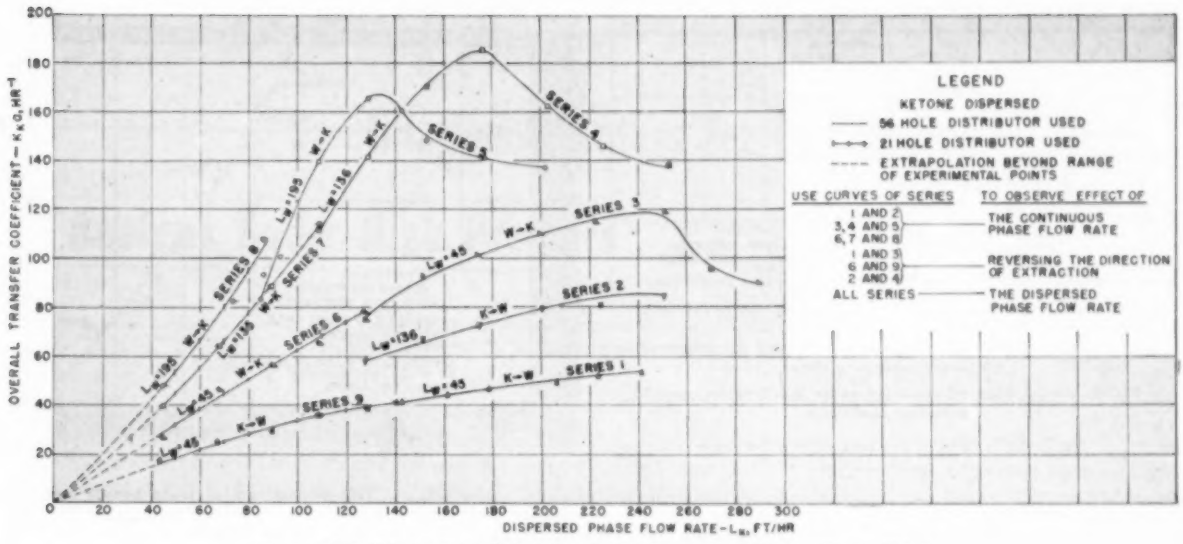

Fig. 4. Effect of flow rates and direction of extraction on over-all extraction coefficient.

the range of flow rates investigated the over-all coefficient passed through a maximum only for the series with the three highest dispersed-phase flow rates.

Data of series 6 and series 17 agree with data of Johnson and Bliss (*8*) within 10%. This indicates that for the case of ketone dispersed there is little difference between the use of a distributor comprising individual tubes and one comprising holes drilled in a plate. Over-all coefficients of series 10, however, fall somewhat lower than those of Johnson and Bliss. Here, water is dispersed and since it wets the distributor surface preferentially, nonuniform drops with some large drops result when the plate-type distributor is used. These nonuniform drops evidently result in less interfacial area than is obtained with the unifom drops formed with the multitip distributor.

Results of the limiting flow studies are tabulated in Table 4 and plotted in Figure 7. Values for the dispersed- and the continuous-phase flow rates at the points where swirling first sets in at the bottom of the tower in runs where ketone was dispersed and no solute was present in the system are given. These values are compared with the flow rates of the runs of series 3, 4, and 5 where the maximum over-all extraction coefficients were observed, runs 18, 21, and 28, respectively. From Figure 7 it is seen that where continuous-phase flow rate is plotted against the dispersed-phase flow rate the two cases almost coincide. Furthermore, in runs 18, 21, and 28 swirling was observed to be just beginning to set in. This is the reason for calling the point where swirling begins to set in the point of limiting flow. As just indicated, it appears that the point of limiting flow is independent of solute content of the system. This result is not in agreement with that of Johnson and Bliss (*8*) who found that the presence of a solute lowered their flooding point flow rates considerably. Also plotted in Figure 7 and tabulated in Table 4 are flooding data of Blanding and Elgin (*3*) for spray towers, and it can be seen from these data that their flooding point corresponds closely to the limiting flow points of the present work.

Conclusions

1. Extraction data on a spray tower operated at higher flow rates than have heretofore been reported have been obtained. The tower was designed with enlarged end sections in accordance with recommendations of previous workers.

2. It has been found that at flow rates where a maximum over-all coefficient exists, a visual phenomenon takes place, i.e., swirling of the dispersed phase sets in at the end of the tower where that phase enters and the region of high dispersed-phase holdup begins to move back into the conical section of the tower. This point is defined as the point of limiting flow.

3. Flow conditions at limiting flow are the same when a solute is present and extraction is taking place as when no solute is present. Thus simple limiting flow studies can be used to predict conditions for optimum extraction.

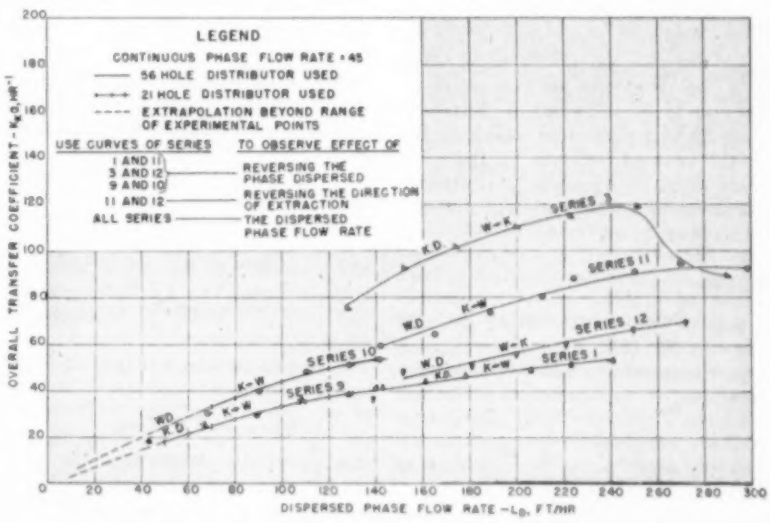

Fig. 5. Effect of dispersed-phase flow rate, direction of extraction, and phase dispersed on over-all extraction coefficient.

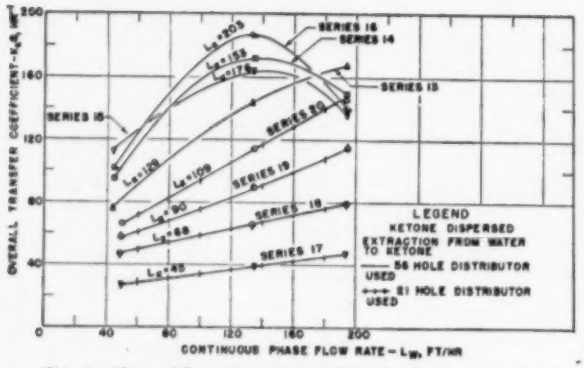

Fig. 6. Above, Effect of continuous-phase flow rate on over-all extraction coefficient.

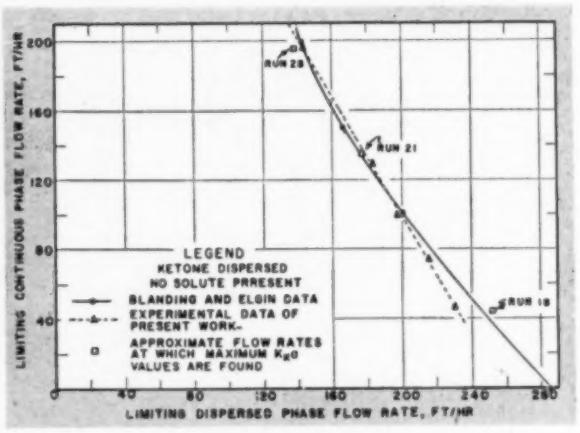

Fig. 7. Right, Effect of solute on limiting flow rates.

Table 4.—Effect of Solute on Limiting Flow Rates

LIMITING FLOW RATES, CU.FT./(HR.)(SQ.FT.)

KETONE DISPERSED

Present Work					Blanding and Elgin (3)- (no solute)	
No solute Series 21		With Solute				
Dispersed	Continuous	Run Number	Dispersed	Continuous	Dispersed	Continuous
230	47.6	18	251	44.9	285	0
213	75.0	21	176	136	200	100
197	100	28	129	195	165	150
183	130				141	200
143	197					

4. Qualitative observations which have been previously reported by other workers have been confirmed: (a) From the standpoint of coalescence it is more desirable to extract from the continuous to the dispersed phase than in the opposite direction, (b) If the phase which wets the distributor surface preferentially is to be dispersed, a distributor made up of a number of individual tips should be used, whereas if the other phase is to be dispersed, a distributor consisting of a flat plate with holes is satisfactory.

Notation

a = interfacial surface area per tower volume, sq.ft./cu.ft.

K_x = proportionality constant of rate equation, $\frac{\text{lb. moles solute}}{\text{(hr.)(sq.ft.)}\left(\frac{\text{lb. mole}}{\text{cu.ft.}}\right)}$

K_xa = over-all extraction coefficient, $\frac{\text{lb. moles solute}}{\text{(hr.)(cu.ft.)}\left(\frac{\text{lb. mole}}{\text{cu.ft.}}\right)}$

C_x = solute concentration in ketone phase, $\frac{\text{lb. moles}}{\text{cu.ft.}}$

C_w = solute concentration in aqueous phase, $\frac{\text{lb. mole}}{\text{cu.ft.}}$

C^*_x = solute concentration in ketone phase that would exist if in equilibrium with solute concentration in aqueous phase, C_w, $\frac{\text{lb. moles}}{\text{cu.ft.}}$

H_f = % holdup of dispersed phase; % of tower volume occupied by dispersed phase

L_c = continuous-phase flow rate, $\frac{\text{cu.ft.}}{\text{(hr.)(sq.ft.)}}$

L_D = dispersed-phase flow rate, $\frac{\text{cu.ft.}}{\text{(hr.)(sq.ft.)}}$

L_x = ketone phase flow rate, $\frac{\text{cu.ft.}}{\text{(hr.)(sq.ft.)}}$

L_w = aqueous phase flow rate, $\frac{\text{cu.ft.}}{\text{(hr.)(sq.ft.)}}$

S = tower cross-sectional area, sq.ft.

v = drop velocity through tower, ft./hr.

N_x = total rate of solute transfer based on ketone phase, $\frac{\text{lb. moles}}{\text{hr.}}$

N_w = total rate of solute transfer based on aqueous phase, $\frac{\text{lb. moles}}{\text{hr.}}$

SUBSCRIPTS

1 denotes bottom of tower
2 denotes top of tower

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Scintillation Counters for Continuous Analysis Under High Pressure

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The availability of radioactive tracers introduces a new tool for high pressure research. The principal advantage of these tracers is that, under appropriate circumstances, it is possible to make continuous analyses inside a high pressure system without sampling. This paper describes methods developed and successfully used in the High Pressure Laboratory at the University of Illinois. While the application here has been primarily to diffusion measurements, other uses will suggest themselves to the individual reader.

The material divides rather naturally into two sections: the principles and methods of scintillation counting, and the development of optical techniques suitable for different materials and different pressure ranges.

Scintillation counters have been used extensively in the fields of physics and radiochemistry, and many papers have been published which discuss their improvements and various uses. In the following is a brief discussion of the scintillation counter used in this laboratory.

Scintillation crystals when exposed to radiation from radioactive materials emit minute fluorescent light pulses. For high pressure work, these pulses are transmitted out of the pressure bomb through a window seal, of which several types are discussed later, to the photosensitive electrode of the photomultiplier tube. This tube serves to convert the light pulses into electronic pulses and feeds the latter to a preamplifier. The signals are further amplified through a linear amplifier and recorded on a scalar along with a mechanical register.

The efficiency of the scintillation counter depends largely on the luminescence of the crystal. In principle, luminescence is a non-equilibrium process in which photons, electrons, protons, ions, and other particles bombard a material and excite some of its atoms or groups of atoms to energy levels considerably higher than those attained by thermal excitation. In returning to lower energy levels, the excited centers emit correspondingly high energy photons which are visible as light.

It is desirable to have the maximum fraction of the energy lost by the impinging particles converted into light energy. In addition, it is best to have the radiated light largely concentrated in the region of maximum spectral sensitivity of the photomultiplier tube and be emitted in a short enough time interval to permit high counting rates. This requires the crystal to be transparent to these light pulses.

Among the crystals possessing these properties, anthracene and cadmium tungstate were found to be the most useful. A comparison of the efficiencies of anthracene, naphthalene, calcium tungstate, cadmium tungstate, and thallium impregnated sodium iodide was made by Timmerhaus *et al* (*7*). Anthracene was found to be efficient for beta and gamma radiation. The strongest emission band for anthracene is at 4400 Å, which is close to the maximum sensitive region of the 1P21 photo-multiplier tube (at 4000 Å). Since anthracene is available in a clear form and is easily cut and sliced into any size, it is used in this laboratory wherever permitted by the chemical properties of the system. Otherwise cadmium tungstate is used because of its comparative inertness.

The temperature effect on the counting efficiency of several scintillation crystals was studied by Minarik and Drickamer (*3*) and by others. The counting efficiency was found to drop with increase of temperature for calcium tungstate and anthracene. Sodium iodide impregnated with thallium, however, was found to change little below 250° C. The counting rate was cut in half for anthracene for each 75° increase in temperature while an increase of 50° produced a similar reduction in counts for calcium tungstate. On the other hand, the sodium iodide is difficult to handle physically.

The effect of pressure on scintillation crystals was studied by Reinsch and Drickamer (*5*). For anthracene no noticeable effect of pressure was found up to 10,000 atm. In the case of cadmium tungstate, a reversible pressure effect of approximately 15 to 20% was noted over the same pressure range. The pressure effect on scintillation crystals is therefore much smaller compared to the temperature effect.

The transmission of the light pulses from the scintillation crystal inside the high pressure bomb consists usually of two steps: first, the light is transmitted through a high pressure window seal and then through a light conducting rod to the photomultiplier tube.

Various types of window seals exist, but only those which are being used extensively in this laboratory will be discussed here. These are most conveniently classified with respect to use and pressure. For gases or liquids covering a pressure range from atmospheric to 350-400 atm. an O-ring with a Lucite rod or window is the preferred seal. For higher pressures to 10,000 atm. sapphire windows using a Poulter seal are used almost entirely. Another seal using a combination of an O-ring and unsupported area seal with a plate glass or quartz window has also proved to be quite effective to 1000 atm.

The first type of window seal mentioned above is described by Timmerhaus *et al* (*8*) and is shown in Figure 1. The actual pressure seal is made by the O-ring around the Lucite or quartz rod. The latter must sometimes be used because gases like carbon dioxide when subjected to pressure tend to attack Lucite and destroy its optical properties. To keep the Lucite or quartz rod from sliding out because of the pressure exerted in the bomb, a shoulder is provided on the rod along with a retaining nut. The length of the shoulder is not too critical. Generally, it is not made any shorter than one-half inch for strength purposes. However, the taper at each end of the shoulder is critical. It has been established quite conclusively that, the larger the

radius of curvature at the ends of the shoulder, the smaller the conducted light losses. This becomes quite important especially for weak radioactive concentrations in the pressure bomb.

When using the quartz rod it has generally been more convenient and considerably cheaper to make the fitting in two parts. The shoulder portion of the fitting is made and polished from an oversize diameter piece of Lucite rod since its machining is relatively easy. The polishing is important since much light would be lost on an unpolished rough-surfaced rod. The portion of the fitting upon which the O-ring seal is made can then be made of a short piece of quartz rod. Light losses at the junction of the two rods can be minimized by a coating of Canada Balsam.

With Lucite rods the upper temperature limit for an effective seal seems to be 60° C. There is no apparent temperature limitation on the quartz within the limits permissible for O-rings.

The scintillation crystal can be sealed to the rod or window with a glue made from Lucite shavings dissolved in ethylene dichloride. This also makes an effective coating for the crystals, which are subject to attack by the paraffin hydrocarbons without appreciably decreasing the efficiency of the crystal itself.

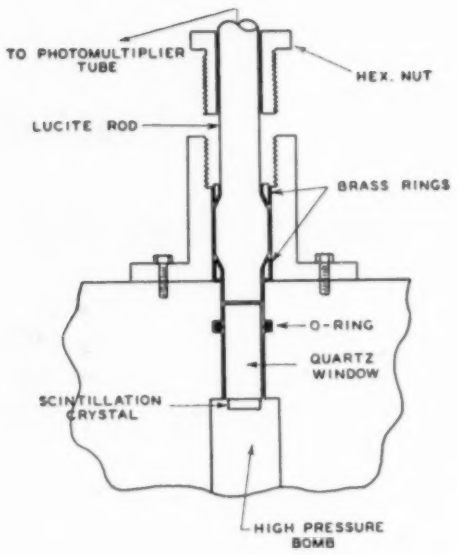

Fig. 1. Cross-sectional view of window seal.
For moderate pressure.

Another type of window seal is used in this laboratory for higher pressures up to 10,000 atm. The original idea of placing the window directly against the metal surface of a window support with no gasket between them must be accredited to T. C. Poulter (*6*). This type of window seal is shown in Figure 2.

The support is made of tool steel heat treated to 52-56 Rockwell C and carefully surface-ground. A flatness of one-quarter wave length of light is desirable. If the window will hang upside down after being pressed on the plug, it will seal. Synthetic sapphire windows with the C-axis of the crystal perpendicular to the flat surface have been found to be superior to any other windows tested and are used exclusively now in this laboratory.

Assembly of the window seal involves cleaning the two contact surfaces carefully and centering the window over the hole in the window support. Vacuum is used to hold the window in place while the outside of the window is cemented to the surface of the support with Duco cement. The main purpose of the cement is to hold the window in place during assembly and before any pressure is applied. Several layers of cement are applied and allowed to dry thoroughly before the final assembly begins.

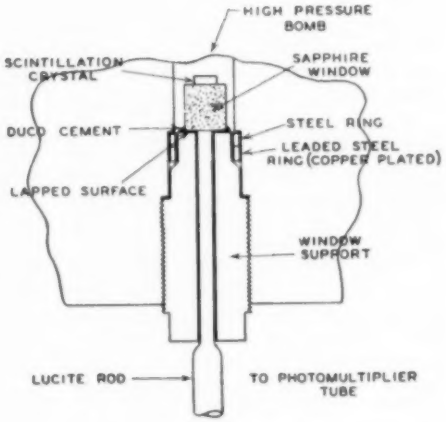

Fig. 2. Cross-sectional view of window seal.
For 10,000 atm.

A glance at Figure 2 again shows that the seal between the window support and the pressure bomb is made by the "Bridgman unsupported area seal." Experience has shown that the dimensions of the leaded steel, copper-plated before assembly, and the hard steel ring are not too critical. In fact, it is best that the fit is a little loose decreasing the tendency to score the rings as the window support is screwed into place.

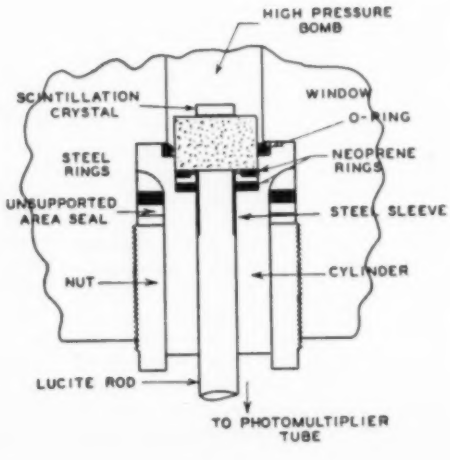

Fig. 3. Cross-sectional view of window seal.
For 2,000 atm.

Another type of window seal used successfully here for gases to 1000 atm. pressure is shown in Figure 3.

The first seal is made by the O-ring seated in the cylinder holding the window and is held in place by the internal pressure of the bomb. The second seal is made by means of a modified Bridgman unsupported area seal. Normally, this type of a seal uses a nut to press down on the sealing rings, tending to spread them out in both directions effecting a seal at low pressures. Then, as the pressure inside the bomb increases, more force is exerted on the sealing rings and cylinder. Because of a difference in areas on the top and bottom of the seal, the pressure on one side of the sealing rings is always greater than on the other. Thus, this makes a tighter seal as the internal pressure is increased. However, since there is no nut to press down on the sealing rings, no seal will be made at the low pressures. Sealing at these pressures is effected by the O-ring seal. As the pressure is increased inside the pressure bomb, more pressure is applied to the window, and, in turn, to the sealing rings. These are made of thin neoprene rubber. The internal pressure causes the neoprene rings, of which there are two, to spread out to make a seal on the one side with the Lucite rod and with the wall of the cylinder on the other side.

Leakage between the cylinder and the pressure bomb is prevented by another Bridgman unsupported area seal. This seal is effected by placing on the shoulder of the cylinder a brass ring, a neoprene rubber ring, and then another brass ring. The rings are forced together by a large nut.

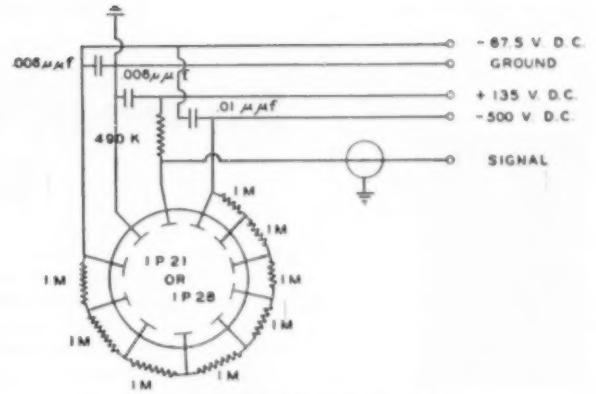

Fig. 4. Photomultiplier tube circuit.

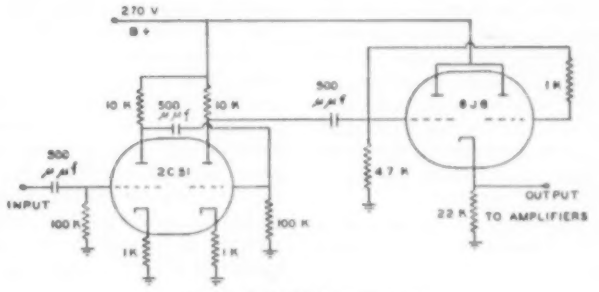

Fig. 5. Cathode follower circuit.

Since light transmission is quite important to the successful operation of the scintillation counter, various transmitting media were tested (*7*). Accordingly, it was found that Lucite at any length is considerably superior in this property to Plexiglas and polystyrene. For Lucite the transmission of light from beta radiation of any energy is about 75% as great at 12 in. as it is at 6 in. Quartz was found to be equivalent to Lucite for anthracene crystals and about 40% superior to Lucite for calcium tungstate crystals. However, since drawn quartz rod is brittle and costly, Lucite rod was used in most of the experiments studied in this laboratory. Another advantage of Lucite is that it can be curved without losing too much light. However, it is important to make the bend as gradual as possible. The quartz is, of course, essential for high temperature work.

The photomultiplier tubes used in this laboratory are mostly 1P21 and 1P28. The phototube and circuit are housed in a brass box and cooled to dry-ice temperature to reduce the background noise of the tube. The detailed construction of this box is given by Timmerhaus (*7*). Although these phototubes have slightly different characteristics and wave-lengths responses, both are used after careful selection for low background noise and a high signal to noise ratio. This is necessary since the tubes, even though manufactured on a mass-production basis, are not uniform in their sensitivity and tube noise.

The tube circuit in use (see Fig. 4), is a modification of that suggested by Sherr (*6*) and modified by Marshall, Coltman, and Bennett (*1*), Timmerhaus (*7*), and Minarik (*2*). The latter found that for maximum signal to noise ratio the optimum resistance to be used varies from tube to tube. Therefore, it is advisable to make a few checks with different valued resistors to obtain the maximum signal to noise ratio.

The preamplifier that follows the photomultiplier circuit should be placed as close to the latter as possible to minimize stray electronic interference. Instead of using a commercially built preamplifier, a cathode follower built in this laboratory may be substituted with the same results. The circuit for this cathode follower is given in Figure 5 because it is a modification of one found in a tube manual. Besides being cheaper, the cathode follower is simpler in design and easier to maintain than the commercial preamplifier.

The linear amplifier and sealer that follow the preamplifier are standard equipment which can be purchased. A new type of sealer which has a built-in linear amplifier is now also being used because of its convenience. All pieces of electronic equipment are carefully shielded and the shielded connections between the different units are grounded to avoid any static noise.

This scintillation counter described above is capable of detecting weak radioactive tracers such as H^3 or C^{14}. This has been a valuable aid in the study of diffusion and thermal diffusion under various conditions of pressure and temperature.

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Presented at A.I.Ch.E. Forty-fifth annual meeting, Cleveland, Ohio.

Why Does the Chemical Engineer Succeed or Fail with People

Richard S. Schultz

Richard S. Schultz, president of Industrial Relations Methods, Inc., has spent more than twenty years as management and industrial relations consultant to varied business organizations and has done special research on personnel appraisal and test techniques. A Ph.D. from the University of Pennsylvania, Dr. Schultz is adjunct professor, Industrial Engineering, Graduate School of Engineering, New York University.

This is the second paper in the Human Relations Symposium presented at A.I.Ch.E. meeting in Cleveland.

In the course of a conversation on personnel appraisal with the president of a manufacturing company employing a considerable number of chemical engineers and other technically trained people, he made this significant statement: "We need men in our company who are willing to pay the price for success. Failure in itself exacts its own toll." This remark was reminiscent of others made about certain personnel in other organizations in the chemical industries.

"We have some men who too readily follow the line of least resistance. They develop lop-sided, they stop growing, and they have only mediocre success. Here is a man of thirty-eight who is brilliant technically, but immature. For him a simple problem becomes an intricate complexity of detail. He is facts and knowledge 'muscle-bound.' He is sociable enough, but he lacks a sense of appropriateness in the more important contacts with people. We notice this shortcoming particularly in executive committee meetings and outside business contacts. His technical enthusiasms carry him away. His department needs leadership. His office is pleasant enough for his associates, but they tell me his men are dissatisfied. We do not see a way that our organization can remedy this situation except by replacing him with another executive who can be more successful with people. If only he would devote more time to managing men rather than immersing himself in technical information."

WHAT do these comments imply? They show that success or failure with people is determined by the degree of effort to acquire specific attitudes, habits, and skills. A mature individual will have developed the essential habits and appropriate standards and manners for varied personal contacts if they are absolutely essential to his success. But the man of thirty-eight to whom we have just referred, who has devoted all these years to acquiring facts and information at the expense of his personality and maturity as an adult, has much to do to overcome his limitations.

Establishing the "Why" of Success or Failure

From three broad sources namely case studies, statistical data, and research and observations, information and evidence can be presented to establish the reasons why chemical engineers succeed or fail with people.

CASE STUDIES

First, when men in the process, chemicals, and related industries are appraised for executive, supervisory, engineering, technical development, research, and sales assignments, comprehensive studies are made of individuals through interviews and personnel tests. An inclusive inventory covers data on home and family background, education and related activities, social, cultural-recreational activities, practical experience and training, military service, abilities and special aptitudes, work habits, interests, ambitions, and personal qualities.

PERSONAL QUALITIES

Special mention should be made here of personal qualities since some of these, such as speaking and writing well, enthusiasm, frankness, poise, self-reliance, confidence, sense of humor, sincerity, and aggressiveness, play a vital role in the first impression a chemical engineer creates, and others like intiative, versatility, general adaptability, and loyalty give an over-all picture of the potentialities of the individual, and, from a long view, his worthwhileness.

STATISTICAL DATA

A tabulation of test-measured ratings based on a sampling of chemical engineers now employed in varied positions, is shown on the chart below.

Thus chemical engineers are mostly high in general intelligence. They rate average or high in technical intelligence, but tend to be lower than in general intelligence. Their interests do not seem to be significantly differentiated. The general pattern is predominantly average or high on technical, economic, or leadership interests.

But in another limited study, evidence

			Dominant Interests or Desires		
	General Intelligence	Technical Intelligence	Technical	Economic	Leadership
	%	%	%	%	%
High	74	31	21	32	15
Average	14	39	65	50	58
Low	12	30	14	18	27

indicates that chemical engineers as a group have specific interests and rate predominantly as follows: scientific, high; computational, above average; mechanical, average; and persuasive, below average.

This brief presentation of statistical data brings up a number of cogent questions. What are the test-rating trends for a specific type of work in which chemical engineers are engaged? For example, what would be the pattern for executives, production supervisors, control chemists, senior research men, project engineers, salesmen, etc.? If we try to portray personality characteristics, such as emotional stability, aggressiveness, sociability, self-reliance, initiative, confidence, and cooperativeness, such data may readily be misleading. It would be again necessary to ask, "Personality for what?" In other words, a presentation of trends on personality tests would be most dependable if based on specific types of positions in which chemical engineers are now engaged.

RESEARCH AND OBSERVATION

From various research studies, fundamental personality characteristics have been established and devices on methods for measuring them are being constructed.

There is one classification of relatively unique traits of temperament or disposition on how a person is likely to react in varied situations. These traits are identified as: active, vigorous, impulsive, dominant, stable, sociable, and reflective.

Another more comprehensive research study revealed more than 150 elementary personality qualities. But further statistical analysis indicated that personality traits could be conceived in terms of clusters or primary combinations. The scientific finding of primary or source traits, listed in pairs, such as: alert - minded - dull, courageous-fearful, frank-evasive, vigorous-fatigued, firm-indecisive, etc., supplies a basis of measuring personality differences as they relate to specific positions and responsibility requirements.

A necessary personality trait or possibly unique ability is to put yourself in the other person's place, establish rapport, and anticipate his thinking, feelings, and actions. It is called empathy. Those individuals, who rate high in this characteristic can more readily understand, predict, and control thinking, feeling, and actions of people. Thus, personality in the nontechnical sense is synonymous with personal-relations aptitude. This means effectiveness in maintaining sustained responsiveness of people. It obviously implies liking people and being more or less liked by them.

THREE MAJOR FACTORS

An appropriate combination of three major factors namely, motivation, ability, and personality, is a significant determinant of success with people. This results in what may be aptly phrased "a style of life" or a balance most conducive to the circumstances in which the individual finds himself. The chemical engineer, in whatever position he may be, is more likely to be effective with people when his motivation is in keeping with his abilities, affording him an opportunity to allow his individuality or personality to mature with age and experience.

MOTIVATION

But the underlying clue to determination of personalities is motivation. We need definite targets to shoot at. The direction which they point and the intensity with which we apply our energies to them show strikingly the dimensions of our personality. On the basis of what we know about the abilities of chemical engineers, their sights or goals during the dominant period of a career should increase with age, experience, and progressive attainment. The industries with which they are associated, particularly chemical and process, are undoubtedly growing, expanding, and progressing. To be in such an environment is in itself a highly motivating influence. Chemical industries are definitely in search of men who can be successful with people. Consequently, to some extent can we not say the fault perhaps lies within ourselves, when lack of success is noted.

Some, especially the advertiser, think of our motivation in terms of basic desires, needs, or interests which will satisfy us as purchaser of products. What value we place on these desires and the order of importance which they have in our thinking and feeling are vital in our careers.

More specifically there is a simple way of broadly classifying our dominant motives, interests or drives:

Type	Principal Desire
Economic	Money, practical affairs
Technical	Scientific or theoretical knowledge
Social	People, group activities, humanism
Leadership	Recognition, status, influence, power
Culture	Aesthetic, artistic, literary
Spiritual	Primarily religious and philosophic

GUIDING PRINCIPLES

The question is often asked what one can do individually to further and assure success with people. But there is no sure-fire, neatly packaged, or easily purchased formula or remedy. However, there are a few guiding principles which should help. These are:

1. Self-perception
2. Empathy
3. Egocentrism
4. Imitation
5. Practice

Self-perception means knowing yourself in the broadest sense. If the question who are you? is asked, an appreciable number of people actually face a mental hazard when they try to put their ideas about themselves into words. Fair and intelligent self-evaluation is difficult. It is interesting to note that many successful executives, salesmen, supervisors, and others whose daily activity is predominantly with people are constantly striving truly to know themselves and are sensibly self-critical.

Thus, self-perception can serve as a guide in adjusting ourselves to our assets and liabilities. Furthermore, by knowing ourselves well, we are more likely to attain our various personal goals as adults.

To put oneself in the other person's place is empathy, referred to previously. Probably one of the most practical and useful guides for success with people, this attribute makes you think, feel, and even review how the other person would act. By the use of this method you are actually doing what the successful executive, salesman, parent, teacher, advertising man, or publicist does. All of them go through trial rehearsal or practice, just as the golf professional makes some shadow moves before he hits the ball. Thus, you not only sense the more appropriate way of dealing with people; but you simultaneously correct and improve your personal - relations techniques.

Reference has been made previously to the subject of interest, but here we are principally concerned with self-interest. For the supreme interest for all is ourselves. Each person inherently is and considers himself the center of the universe. This is known as egocentrism. It is the first and deep-rooted principle of human nature. "What's in it for me?" is stating egocentrism quite bluntly.

Another point to stress here is that the man most successful with people is well informed about people. He neglects little knowledge about others, knowing their habitats, whims, and egocentricities. In other words, he puts this law of self-interest to work practically.

Another method by which we learn to be successful with people is imitation. The child acquires his social skills at home and at school with playmates. As he grows older what is more apparent than patterning his feelings, thinking, and actions on those of his associates. Our skillfulness with people can be

enhanced by opportunities we take to imitate habits and actions of those with high personal-relations aptitude. *Be* and *do* what you want others to *be* and *do* is a guiding rule in one's daily relations with others.

The preceding guide points—self-perception, empathy, egocentrism, and imitation can be significant to your success with people only if you practice with unrelenting consistency every day to acquire such skills. This means doing generally what you would do in acquiring any complex habit or skill, and, especially it means devoting time, effort, and thought. Progress in acquiring a habit is not a smooth process. We learn by mistakes, though if we persist in practice, performance improves, and success begets success. If you begin improving your personal-relations habits in one respect, it becomes much easier to acquire others and more complex ones.

How does one get started on a program of improving his skills so that he can be classed a success with people? There are three primary tasks in getting started properly.

First, place yourself in this circumstance. Assume a group of your professional colleagues, associates, or friends have had occasion to be talking about you. Somehow, unseen you overhear a final remark about yourself:

What could they say that would please you more than anything else?

Try to visualize the situation clearly. Concentrate on this crucial question for several minutes. Then write down the one or more thoughts or impressions you most prefer people to have about you. What you say will be a revelation to you, if you take time to reflect. It will indicate your ideals, inner desires, and drives. It is in a direct way a clue to your real goals in life.

The second task is concerned with how much your interests and thoughts extend beyond immediate matters of daily work and necessities of living. Are you sufficiently inquisitive about what is going on, and relating yourself to the wider worldly scheme of things? As an adult do you have a reasonably sensible guiding philosophy of life? Your strengths or weaknesses are subtly and intricately determined by your perspective—beyond a mere "bread, butter and shelter existence." This is the sustaining foundation of maturity and durable practical success with people.

Finally, this author would like to recommend a list of twenty Success Habits,* aimed solely at making more effective your personal-relations skill.

It is evident that success in dealing with people is determined by a multiplicity of variables. Surface qualities, the popular conception of the "brassy" personality, or the effervescent social mixer do not accurately portray the essential ingredients for a successful relationship with people. Actually in such instances, a lack of self-sufficiency may ultimately result in lowering an individual's personality effectiveness.

Also, it is not surprising to come upon outstanding people with only mediocre or almost nondescript personalities. Yet in their true selves, they are humble, congenial,' considerate, reasonably well adjusted, purposeful, and effective in their chosen endeavors.

What does it all add up to? What are some practical lessons or conclusions which can be drawn from this study?

One major finding which can be drawn from the analysis of hundreds of individual case studies of men with chemical engineering degrees, points up the fact that success or failure with people is not inevitable or complete for any person. There is a relative scale or continuum of success, which can range in percentage points from a low toward zero to a high toward 100. At the lower end of the scale are the technician, research man, the desk-worker, and others who have practically no contact with people. Up the scale are the salesman, supervisor, and executive whose duties and assignments are constantly with and through people.

Regardless of our daily occupation we are always in a people situation—on the job, at home, socially, and in the community; there are always the storekeeper, the bus driver, the waiter, or the newspaper boy, all the people around us who justify the assumption that one is successful because of people. There is no such thing as a non-people vacuum. You do not and can not succeed in isolation.

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CORRECTIONS

In "Equilibrium Conditions of Flash Vaporization of Petroleum Fractions" by Wayne C. Edmister and John R. Bowman appearing in *Chemical Engineering Progress Symposium Series No. 3, Phase-Equilibria—Minneapolis and Columbus*, 48, 46 (1952), the following corrections should be made: In Table 1, page 50, the last two entries in the second column should read 632 and 1434 mm. Hg instead of lb./sq.in.; in the Notation, page 51, M_1 and M_v should be M_L and M_V; on pages 47 and 48 *ae* and *ai* should be a_e and a_i, and X_f and Y_f should be x_f and y_f.

Sulfur-Gas Thermodynamics

Gamson and Elkins' approach (*3*) to sulfur-gas thermodynamics is based on the supposition that the hypotheses which have been proposed to explain the peculiar compressibility of sulfur gas are a necessary ingredient of thermodynamic calculations. The unusual compressibility of this gas certainly calls for explanation, and no better hypothesis than that of molecular aggregation has been proposed. However, although this is of great interest in physical chemistry and in chemical kinetics, thermodynamically it is irrelevant. Thermodynamics is not concerned in the least with the mechanism of compressibility, but only with the fact.

Although it was not emphasized in the article, Dr. Gamson in discussion at the Atlanta meeting of A.I.Ch.E. expounded his conviction that a thermodynamically sound calculation of sulfur gas equilibria must give explicit recognition to the different "driving forces" of the various molecular species. I shall attempt to develop the opposite conclusion.

The only observations that have been made are PVT measurements on sulfur, that is, on the total gas. All the reported compositions of sulfur gas, the number and concentrations of the various species postulated, the heats of transition between species, and the free energies of transition based on these heats are no more, thermodynamically, than hypotheses proposed to account for the observed PVT behavior of the total gas. A careful reading of Preuner and Schupp's work (*5*) as well as of two

later publications in this field (*2, 4*) should convince anyone that the sum total of these authors' contributions to thermodynamics (not physical chemistry) is PVT data on sulfur.

These data have been statistically analyzed into various assortments of molecular species; but what thermodynamic compulsion is there for singling out sulfur gas to be treated as a mixture of perfect-gas species? In those regions of state where other gases deviate appreciably from perfect-gas behavior, thermodynamic demands are met by use of the fugacity of the total gas. Is it certain that these gases do not also aggregate into complexes of molecular species? There is abundant evidence that they do (*1*). This concept of aggregation in all gases is interesting as an idea in physical chemistry, but its thermodynamic impact is zero.

Statistical analyses of sulfur-gas PVT data can never produce anything from a thermodynamic viewpoint except an equation of state (however circuitous) for the total gas. It would seem advantageous, therefore, to base the thermodynamic treatment of sulfur-gas reactions on the observed PVT data of sulfur gas. Not only is there no "inherent error" in this approach, contrary to Gamson and Elkins, but it is, I believe, the only theoretically unassailable procedure that can be followed.

Now that the PVT behavior of sulfur gas has been placed on a somewhat more secure footing (*2, 4*) it seems desirable to develop the fugacity and other thermodynamic functions directly from the observed PVT, as has been done for other gases. In the meantime, however, sulfur-gas reactions must be calculated.

When fugacity is not available, some other PVT function which is unambiguously related to fugacity can be used in its stead as a correlation device for experimental reaction-equilibrium data. The compressibility factor, for example, was the directly observed quantity and is readily available. It is the reciprocal of v used in all the published papers (*2, 4, 5*) as well as of the x of Gamson and Elkins' Equation (19).

At constant sulfur partial pressure the distribution of species will change with temperature, and Dr. Gamson contends that therefore an equilibrium constant based on the partial pressure of the total sulfur gas could not be expected to reflect the altered driving forces of the molecular species.

In an examination of this viewpoint, it will hardly be argued that an equilibrium constant derived from the fugacity of sulfur, if this were available, would be inadequate for representing a sulfur-gas equilibrium. To do so would be to doubt the whole structure of chemical thermodynamics. Such an equilibrium constant may be called K_f.

It is also possible to write an equilibrium constant in terms of sulfur partial pressure and the compressibility factor. This may be called K_p.

It is not difficult to show for the reaction being discussed that K_p and K_f can never have the same numerical value; failure to recognize this fact betrayed Gamson and Elkins into the dilemma of their Equation (*26*). Their Equation (*25*) is invalid, and the whole statement is tautological. Dr. Gamson argues that there could be two (or more) values of K_p corresponding to the same value of K_f. It can be shown that K_p is single-valued with respect to K_f by demonstrating that dK_p/dK_f cannot become zero.

For the stoichiometry of the reaction, sulfur gas may be regarded as composed exclusively of the species S_1. (It is immaterial what species is chosen, as only numerical values will be affected.) The compressibility factor for S_1 is now $n(=1/v)$. If, however, for purposes of equilibrium the problem is thought of in terms of perfect gas, and partial pressures are used, equilibrium requirements can be satisfied by a reduction in the number of moles of sulfur in the ratio $n:1$. (This is actually what is done when sulfur is regarded as a mixture of perfect-gas species.) This equilibrium gas is now considered to have a molecular weight of $32/n$; it can be called S_e; and its partial pressure, P_e. Then after some computation the equilibrium constant for the reaction under discussion will be

$$K_P = A(P_e)^{3n} \tag{1}$$

The reader is referred to Gamson and Elkins' article for the meaning of A.

For a total pressure of 1 atm., when the partial pressure of S_e is replaced by the fugacity of S_1 in Equation (1), the compressibility will have been taken into account, and that equation will become

$$K_f = A(f)^3 \tag{2}$$

where f is the fugacity of S_1.

From Equations (1) and (2)

$$K_P = K_f(P_e^n/f)^3 \tag{3}$$

and

$$\frac{dK_P}{dK_f} = \frac{d[K_f(P_e^n/f)^3]}{dK_f} \tag{4}$$

$$= K_f \frac{d(P_e^n/f)^3}{dK_f} + (P_e^n/f)^3 \tag{5}$$

Equation (5) will become zero if

$$\frac{d(P_e^n/f)^3}{dK_f} = -\frac{(P_e^n/f)^3}{K_f} \tag{6}$$

or

$$\frac{d(P_e^n/f)^3}{(P_e^n/f)^3} = -\frac{dK_f}{K_f} \tag{7}$$

$$d \ln (P_e^n/f)^3 = -d \ln K_f \tag{8}$$

$$3d (\ln P_e^n - \ln f) = -d \ln K_f \tag{9}$$

$$3d(n \ln P_e) - 3d \ln f = -d \ln K_f \tag{10}$$

From the definition of fugacity

$$RTd \ln f = VdP$$

and from the definition of n, as the compressibility factor for S_1

$$V = nRT/P$$

and consequently

$$RTd \ln f = (nRT/P)dP \tag{11}$$

or, since P is the sulfur partial pressure,

$$d \ln f = nd \ln P_e \tag{12}$$

Substituting from Equation (12) into Equation (10):

$$3nd \ln P_e + 3 \ln P_e dn - 3nd \ln P_e = -d \ln K_f \tag{13}$$

$$3 \ln P_e \, dn = -d \ln K_f \tag{14}$$

Since the possibility that K_p may be ambiguous at constant sulfur partial pressure is being considered, Equation (14) can be integrated at constant pressure:

$$3 \ln P_e \int dn = -\int d \ln K_f \tag{15}$$

$$3 \ln P_e(n - n_o) = \ln K_{f_o} - \ln K_f \tag{16}$$

$$P_e^{3(n-n_o)} = K_{f_o}/K_f \tag{17}$$

If the lower limits of integration are taken as the conditions at the lowest temperature for which there is any factual knowledge, then it is known from experience with the reaction that K_{f_o} will be greater than K_f at any higher temperature. Likewise, from PVT data, n_o will be smaller than n for any higher temperature. Consequently K_{f_o}/K_f is greater than one; and, since $3(n - n_o)$ will be positive, P_e must be greater than one. This is impossible, since it requires the sulfur partial pressure to exceed the system pressure.

Consequently, dK_p/dK_f cannot become zero, and hence there cannot be two values of K_f corresponding to the same value of K_p.

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E. R. McCARTNEY

Altadena, California

PLASTICS EQUIPMENT REFERENCE SHEET

RAYMOND B. SEYMOUR and ROBERT H. STEINER

The Atlas Mineral Products Co., Mertztown, Pa.

NEOPRENE RUBBER: Compounded uncured polychloroprene is available as coatings, troweling cements, and tank linings. Cured neoprene is available in a wide variety of mechanical goods, such as hose, tubing, gaskets, and diaphragms.

APPLICATION AND REMARKS: Coatings requiring the addition of an accelerator and other compounding ingredients before use may be brush- or spray-applied to properly cleaned and primed steel, concrete, or wood surfaces. Films as thick as 5 mils per coat are usually applied. However, special compositions can be applied as film three or four times this thickness. A minimum thickness of 60 mils is recommended for complete immersion in corrosive media but thinner films are satisfactory for protection against fumes, vapors, or occasional splash and spillage of corrosive liquids. These coatings require a curing period of several days at room temperature or shorter periods at elevated temperatures to attain their maximum chemical and abrasive resistance. Heavy-bodied trowel cements or putties are available for filling voids in severely eroded metallic equipment. Recently developed "self-curing" neoprene coatings have been suggested as maintenance coatings but are not recommended for continuous exposure to corrosive liquids. Uncured neoprene sheet linings can be field- or shop-applied on properly prepared steel surfaces by trained applicators. Cured neoprene hose, gaskets, and other mechanical goods are available for use in process industries where superior oil, temperature, and chemical resistance is required.

CHEMICAL COMPOSITION: Modified polymers of chloroprene compounded with fillers, such as carbon black, stabilizers, curing agents, accelerators, pigments, etc. Several different types of neoprene are available for specific end uses. Data given below are based on completely cured compounded neoprene coating material.

TEMPERATURE LIMITATIONS: Although specific neoprene formulations give satisfactory service at temperatures up to 200° in non-corrosive service, neoprene is not usually recommended for continuous use at temperatures above 160° F.

A TYPICAL NEOPRENE COATING

MECHANICAL AND PHYSICAL PROPERTIES

Tensile strength, lb./sq.in. @ 77° F.	1600
Elongation, % at break	300
Hardness, Type A Shore Durometer	65
Specific gravity	1.50
Water absorption, 4 days in boiling water, %	10

CORROSION RESISTANCE

	C	H
ACIDS		
Acetic, 10%	F	N
Acetic, glacial	N	N
Benzene sulfonic	E	E
Benzoic	E	E
Boric	E	E
Butyric	F	N
Chloroacetic	F	N
Chromic, 10%	N	N
Chromic, 50%	N	N
Citric	E	E
Fatty acids (C8 and up)	F	N
Fluosilicic	E	E
Formic	G	F
Hydrobromic	N*	N*
Hydrochloric	N*	N*
Hydrocyanic	E	E
Hydrofluoric	N*	N*
Hypochlorous	N	N
Lactic	E	E
Maleic	G	F
Nitric, 5%	F	N
Nitric, 20%	N	N
Nitric, 40%	N	N
Oleic	F	N
Oxalic	E	E
Perchloric	E	N
Phosphoric	E	F
Picric	P	N
Stearic	G	F
Sulfuric, 50%	E	F
Sulfuric, 70%	N	N
Sulfuric, 93%	N	N
Oleum	N	N
Mixed acids, 20% HNO_3 55% H_2SO_4	N	N
ALKALIES		
Ammonium hydroxide	E	E
Calcium hydroxide	E	E
Potassium hydroxide	E	E
Sodium hydroxide	E	E

	C	H
ACID SALTS		
Alum	E	E
Ammonium Cl, NO_3, SO_4	E	G
Copper Cl, SO_4	G	F
Ferric Cl, SO_4	F	N
Nickel Cl, SO_4	E	G
Stannic Cl	G	F
Zinc Cl, SO_4	G	F
ALKALINE SALTS		
Barium sulfide	E	E
Sodium bicarbonate	E	E
Sodium carbonate	E	E
Sodium sulfide	E	E
Trisodium phosphate	E	E
NEUTRAL SALTS		
Calcium chloride	E	E
Calcium sulfate	E	E
Magnesium Cl, sulfate	E	E
Potassium Cl, NO_3, SO_4	E	E
Sodium Cl, NO_3, SO_4	E	E
GASES		
Chlorine wet	N†	N†
Chlorine dry	N†	N†
Sulfur dioxide wet	E	E
Sulfur dioxide dry	E	E
Hydrogen sulfide	E	E
ORGANIC MATERIALS		
Acetone	N	N
Alcohols, methyl, ethyl	E	F
Aniline	N	N
Benzene	N	N
CCl_4	N	N
Chloroform	N	N
Ethyl acetate	N	N
Ethylene, chloride	N	N
Formaldehyde, 37%	E	E
Gasoline	G	F
Phenol	N	N

	C	H
Refinery crudes	G	F
Trichloroethylene	N	N
PAPER-MILL APPLICATIONS		
Kraft liquor	E	E
Black liquor	E	E
Green liquor	E	E
White liquor	E	E
Sulfite liquor	E	E
Chlorite bleach	N†	N†
Alum	E	E
PHOTOGRAPHIC INDUSTRY		
Developers	E	G
Silver nitrate	E	G
General use	E	G
FERTILIZER INDUSTRY		
General use	E	E
STEEL INDUSTRY		
Sulfuric acid pickling	E	E
Hydrochloric acid	N*	N*
H_2SO_4 - HNO_3 pickling	N	N
TEXTILE INDUSTRY		
General use	E	E
Hypochlorite bleach	N†	N†
FOOD INDUSTRY		
General use	E	E
Breweries	E	E
Dairies	E	E
MISCELLANEOUS INDUSTRIES		
Plating	E	E
Petroleum	G	F
Tanning	E	E
Oil and soap	G	F
Water and sewer	E	E

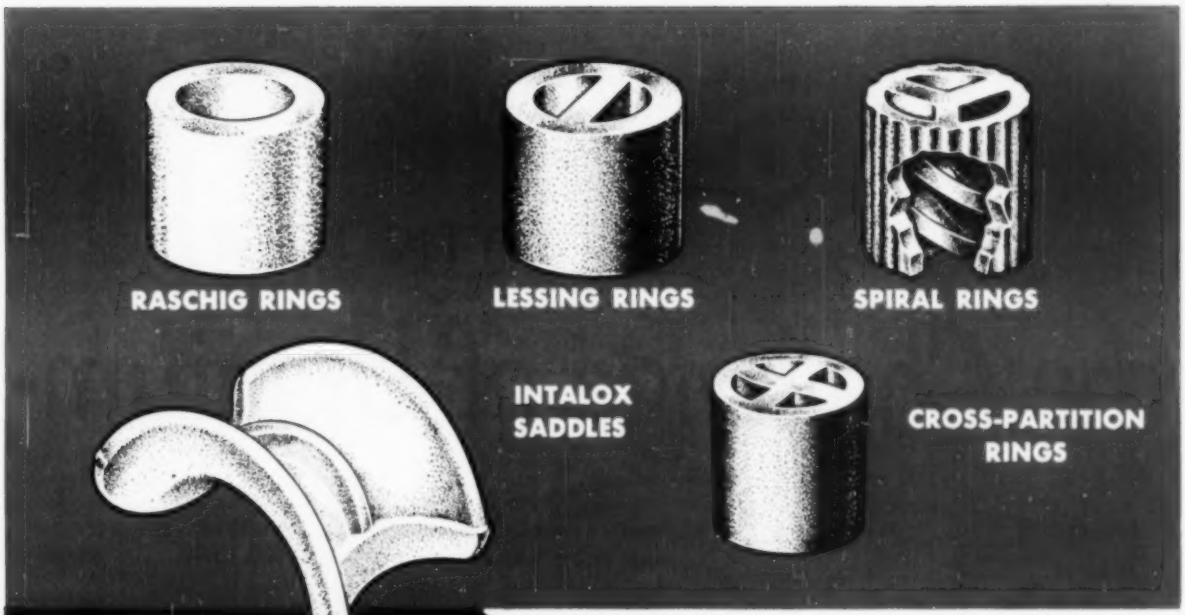
* Permeation with concentrated solutions. Plant tests required before use.
† Surface hardening. Plant tests required before use.

RATINGS:

E—No attack
G—Appreciably no attack
F—Some attack but usable in some instances
P—Attacked—not recommended

N—Rapidly attacked
C—Cold—75° F.
H—Hot—160° F.

No. 25



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U. S. Stoneware offers a range of types and sizes of Tower Packings not even remotely approached by any other manufacturer . . .

INTALOX SADDLES
Unique design minimizes "pattern" packing, blocking, or nesting in dumped beds. Appreciably greater surface area. Lower pressure drop. Higher flooding limits. Made in ½" ¾", 1", 1½" and 2" sizes in both high-fired chemical porcelain and chemical stoneware.

RASCHIG RINGS
Low initial cost. Most widely used of all tower packings. Made in chemical porcelain, chemical stoneware, carbon, steel and other alloys. Size range from ¼" to as high as 6", depending upon material. Sizes up to 2" are generally dumped. Larger sizes, stacked.

LESSING RINGS
A modification of the Raschig Ring. The ring has a single partition or web added to the inside. Made in 1", 1¼", 1½" and 2" sizes in chemical porcelain or chemical stoneware. Usually dumped.

CROSS-PARTITION RINGS
A further modification of the Raschig Ring. Two inside webs cross each other at right angles to create a "4-cell" ring. Cross-Partition rings are made in 3", 4" and 6" sizes in chemical stoneware. They are usually stacked in the tower.

SPIRAL RINGS
Made in single, double or triple spiral types. The function of the spirals is to increase the turbulence of the gas stream. Made in chemical stoneware in 3¼", 4" and 6" sizes. Spiral rings are used in stacked beds.

All U. S. Stoneware ceramic tower packings are made from bodies especially developed for tower service. They are extremely tough, possess high resistance to spalling and exceptional corrosion-resistant properties. Chemical porcelain bodies are completely iron-free and are of zero porosity.

E11-D

The U. S. STONEWARE Co.
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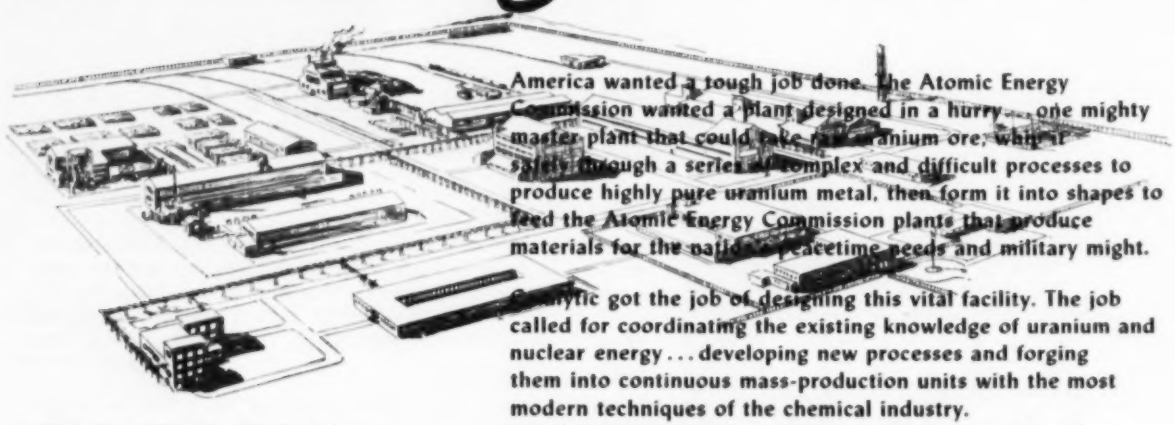
CATALYTIC MEETS

the Challenge of Uranium-



Artist's conception of Feed Materials Production Center at Fernald, Ohio, whose initial operations were announced by the Atomic Energy Commission on May 15, 1953.

America wanted a tough job done. The Atomic Energy Commission wanted a plant designed in a hurry... one mighty master plant that could take raw uranium ore, whirl it safely through a series of complex and difficult processes to produce highly pure uranium metal, then form it into shapes to feed the Atomic Energy Commission plants that produce materials for the nation's peacetime needs and military might.

Catalytic got the job of designing this vital facility. The job called for coordinating the existing knowledge of uranium and nuclear energy... developing new processes and forging them into continuous mass-production units with the most modern techniques of the chemical industry.
It called for designing hundreds of items of special and novel equipment not available on the open market.

Catalytic met the challenge of time and skill and designed the 1050-acre, seventy-eight million dollar Feed Materials Production Center at Fernald, Ohio. Automatic remote-control equipment processes the uranium materials through the intermediate chain of products... UO_3... UF_4... and finally to metal ingots, rods and slugs which are the working material for atomic energy plants. Recovery of expensive chemicals and valuable scrap materials was an important part of Catalytic's job.

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Procurement • Construction • Plant Operation
Revamp of Existing Facilities • Plant Maintenance

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A. I. Ch. E. Questionnaire Correlations on Diverse Subjects

Lloyd B. Smith, J. A. Polack, and G. E. Montes

Several correlations showing the earning capacity of chemical engineers, their experience, and job satisfaction were printed in the July issue of Chemical Engineering Progress, page 17. In the article beginning on this page correlations on various other subjects, which have been frequently under discussion, are presented. This type of analysis will be continued and results reported in a subsequent article. Owing to space limitations only a part of the study is presented this month. Subsequent articles will give analyses of other questions. At the annual meeting this December in St. Louis, a panel of officers and committee chairmen will discuss the meaning of the results in the light of Institute planning.

One of the revealing observations made from an analysis of the responses to the A.I.Ch.E. Questionnaire comes not from the replies to the questions but from a review of the mailing list. The fact that 93% of the members in the United States are clustered in the industrial areas in twenty-two states and the other 7% scattered over twenty-six states may cast a light on some of the opinions expressed and on some of the problems that are of concern. In Table 1 the geographical distribution of the membership is shown by states grouped according to range of membership. Thus, in Group A there are three states (New Jersey, New York, and Pennsylvania) with 3,605 members, about 30% of the total membership of the Institute.* The next two most populous states are widely scattered geographically, California with 795 members and Texas with 872 members. The other states are grouped similarly. All those with more than 100 members number only twenty-two and have a total membership of 10,826. In the other twenty-six states, each with a total membership of less than 100, there are only 839 members. An effort will be made (in another article) to determine whether geographical distribution affects some of the opinions expressed.

Moreover it would seem that local-section activities and the question of growth would have to be considered on a state-wide basis in some areas. Institute problems may require different approaches in Delaware with 582 members and in Wisconsin with sixty-nine. Election procedures may also be viewed differently, depending upon location.

At the time of mailing out the Questionnaires, the approximate distribution of members by type of membership was 38.6% Active, 5.4% Associate, and 56% Junior. The replies received from each of these groups are enumerated in Table A.

Not much difference appears in the percentage return based on grade of membership. Apparently a chemical engineer behaves like one irrespective of the membership label. This was noted in several other correlations. As one might suspect, grade of membership is not a significant basis for correlating general opinions, except where grade

* Figures taken from the roster of September, 1952.

Table A

Grade of Membership	Questionnaires Mailed		Replies Received	
	Number	Per cent	Number	Per cent
Active	4,679	38.6	2,956	62
Associate	665	5.4	459	69
Junior	6,743	56.	4,324	64.4
Total	12,087	100.	7,739*	Avg. 64.4

* Actual total received was 7,802. Improper marking caused I.B.M. rejects.

Table B

THOSE WHO SAID VERY WELL	THOSE WHO SAID WELL ENOUGH	THOSE WHO SAID NOT VERY WELL
28.5% of consultants	66.1% of managers	32.7% of economists
21.2% designers	60.5% of groups	29.7% of plant operators
19.4% of the teachers	58.6% of designers	28.1% of sales engineers
16.9% of research & development groups	57.4% of research & development groups	27.3% of managers
15.4% of plant operators	56.0% of teachers	24.8% of consultants
15.2% of sales engineers	54.3% of economists	24.7% of miscelaneous groups
11.7% of miscellaneous groups	52.3% of sales engineers	22.7% of research & development groups
9.3% of economists	51.5% of plant operators	21.3% of teachers
1.3% of managers	41.5% of consultants	18.2% of designers

The numbers participating in the replies listed above were

		%
a. Research and development	2,511	33.3
b. Design groups	1,145	15.2
c. Plant operators, etc.	1,801	23.9
d. Teachers, etc.	366	4.9
e. Consultants	193	2.6
f. Economists, etc.	162	2.2
g. Sales, etc.	388	5.2
h. Placement, training, etc.	31*	.4
i. Management	700	9.3
j. Special services, etc.	66*	.8
k. Other unlisted fields	162	2.2
	7,525	100.0

Similarly from Part C, the replies are listed from the four largest groups named:

THOSE WHO SAID VERY WELL	THOSE WHO SAID WELL ENOUGH	THOSE WHO SAID NOT VERY WELL
27.6% of self-employed	55.4% of employees of private firms	27.3% of Federal Government employees
20.2% of teachers	54.8% of teachers	26.0% of self-employed
18.8% of Federal Government employees	49.3% of Federal Government employees	24.4% of private firm employees
17.1% of private firm or corporation employees	42.5% of self-employed	22.1% of teachers

The number of responses represented in Part C comparisons were:

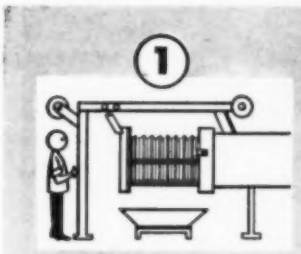
181 self-employed.
6,661 employees of private firms or corporations.
282 employees of the Federal Government.
402 employees of educational institutions.

* Not included in the analysis.

Table 1.—Geographical Distribution of Membership by States (September, 1952)

State	Group Number	Number of States	Numerical Range of Membership	Membership per State	Total No. of Members per Group	Avg. No. of Members per Group	Total Members	Group % of Total	
New Jersey	A	3	1000 to 1500	1501					
New York				1028					
Pennsylvania				1076	3605	1202	3605	29.8	
California	B	2	750 to 1000	795					
Texas				872	1667	833	5272	13.8	
Delaware	C	3	500 to 750	582					
Illinois				691					
Ohio				733	2006	668	7278	16.6	
Louisiana	D	6	250 to 500	264					
Massachusetts				387					
Michigan				381					
Missouri				337					
Tennessee				261					
West Virginia				432	2062	344	9340	17.1	
Alabama	E	8	100 to 250	105					
Connecticut				192					
Indiana				241					
Kentucky				151					
Maryland				238					
Oklahoma				229					
Virginia				156					
Washington				174	1486	186	10,826	12.3	
Total (States over 100 Members)	—	22	100 to 1500	....	....	....	10,826	89.6	(93% excluding foreign)
Arizona	F	26	< 100	6					
Arkansas				37					
Colorado				63					
District of Columbia				63					
Florida				55					
Georgia				79					
Idaho				29					
Iowa				35					
Kansas				60					
Maine				12					
Minnesota				80					
Mississippi				15					
Montana				10					
Nebraska				8					
Nevada				15					
New Hampshire				10					
New Mexico				23					
North Carolina				40					
North Dakota				9					
Oregon				15					
Rhode Island				21					
South Carolina				42					
South Dakota				2					
Utah				24					
Vermont				2					
Wisconsin				69					
Wyoming				15					
Total (States < 100 members)		26			839	....	839	6.9	(7% excluding foreign)
Canada 152, others outside U. S. = 270	..	..	..	422	422	....	422	3.5	
Total Members	..	..	..	12,087	....	....	12,087	100.	

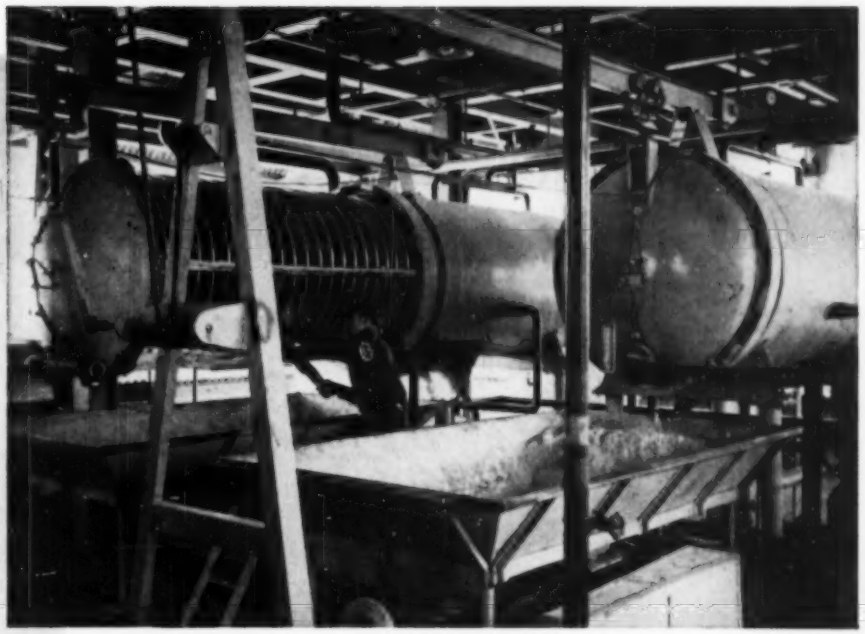
(*Continued on page 44*)



One motion unlocks the quick-opening filter cover. The all-metal leaves roll out of the filter as a unit.

Operator taps leaves to drop cake into trough, hopper or wagon for recovery or disposal.

Then he returns clean leaves into filter. The cover locks pressure-tight with one swift motion.



Large-capacity filter

is easy to clean between cycles

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ALLOY CONSTRUCTION—AT LOWER COST—Because of its simple fabricated design, you can have the Niagara Filter in stainless steel and other alloys, for corrosion resistance, at low cost. Special linings are available, too.

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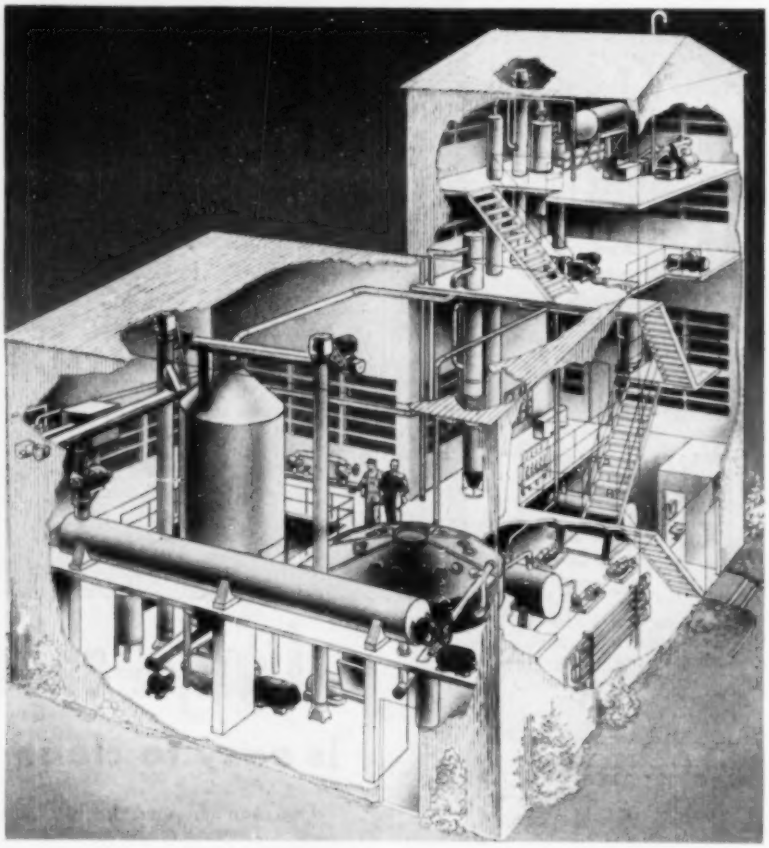
NEW SOLVENT-EXTRACTION PROCESS FOR OILSEED



Cutaway drawing of the Mississippi Cottonseed Products Co. plant for filtration extraction of cottonseed oil. Developed by Lukens Steel Co., the plant will require only two operators a shift for seed cooking and oil extraction. A 150-ton plant fits into a 20- by 45- by 40-ft. space.

A new process of direct solvent extraction for oilseed, called filtration extraction, will be utilized by the new Mississippi Cottonseed Products Co. package plant now at Greenwood, Miss. Requiring no prepressing, the process is designed to replace the hydraulic-type milling process and, according to Lukens Steel Co., designers of the plant, will net $250,000 yearly over the older type of plant with the same 150-ton capacity. Plants with 75-, 100-, and 125-ton capacities are also available from Lukens.

Filtration extraction for oilseed was developed through the pilot-plant stage at the Southern Regional Research Laboratory of the Department of Agriculture. Cottonseed, rice bran, and soybeans were tested in sixty-four runs, and results were compared with those of earlier processes. On the basis of these results plants have been designed for the process by three firms.

Much of the preparation equipment used by hydraulic mills can be retained in filtration extraction with minor changes. The rolled flakes are cooked and then cooled and crisped by evaporation. The oil is then brought into solution in a mixing vessel, and the miscella is removed in a standard continuous filter such as the Oliver horizontal rotary filter. These units replace the extractor and presses of other solvent-extraction methods. The oil is dissolved in the mixing vessel by soaking of properly prepared material with miscella for 15 to 20 min. The slurry of meal in concentrated miscella of about 30% oil is fed to the filter, where the miscella is filtered off and the meal is countercurrently washed and drained three times. The residual oil in the extracted meal or marc, amounts to 1% or less.

Vacuum drainage before and after each wash on the filter results, according to Government engineers, in a lower solvent content of both extracted meal and final miscella and allows a lower solvent-to-meats ratio, lower steam costs, and use of smaller equipment than with conventional processes. For example, the 3-ft.-diam. pilot-plant

(*Continued on page* 56)
(*More News on page* 51)

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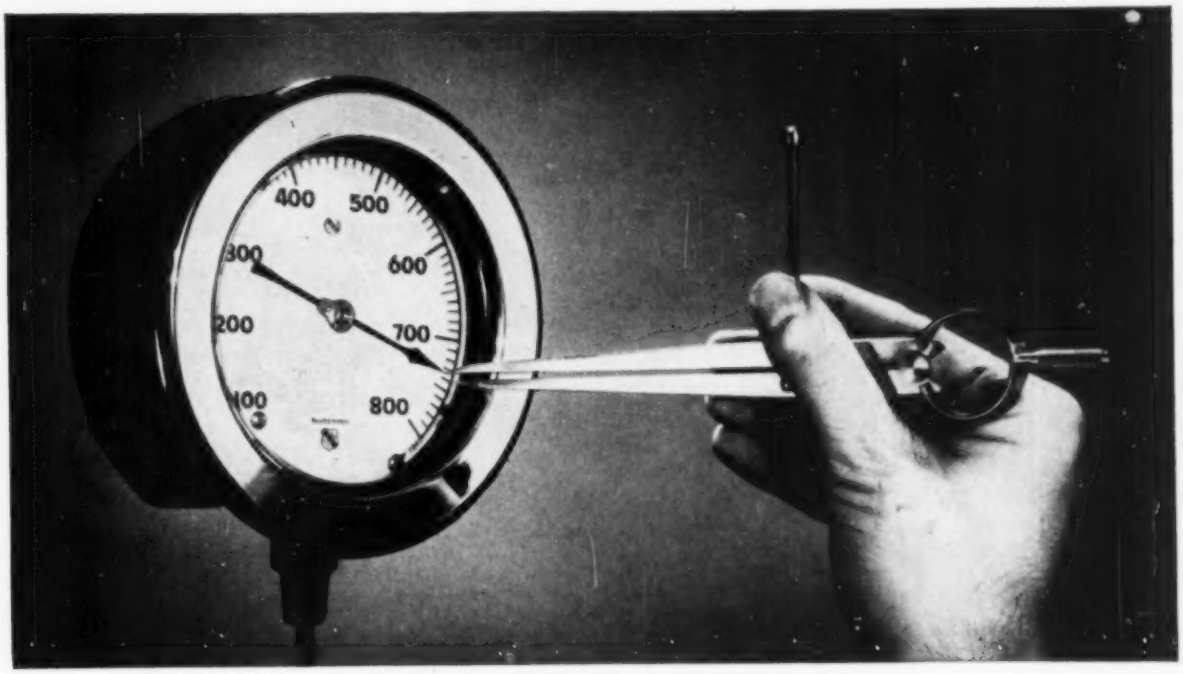
with DOWTHERM, heat can be controlled within fractions of a degree at temperatures up to 750°F.



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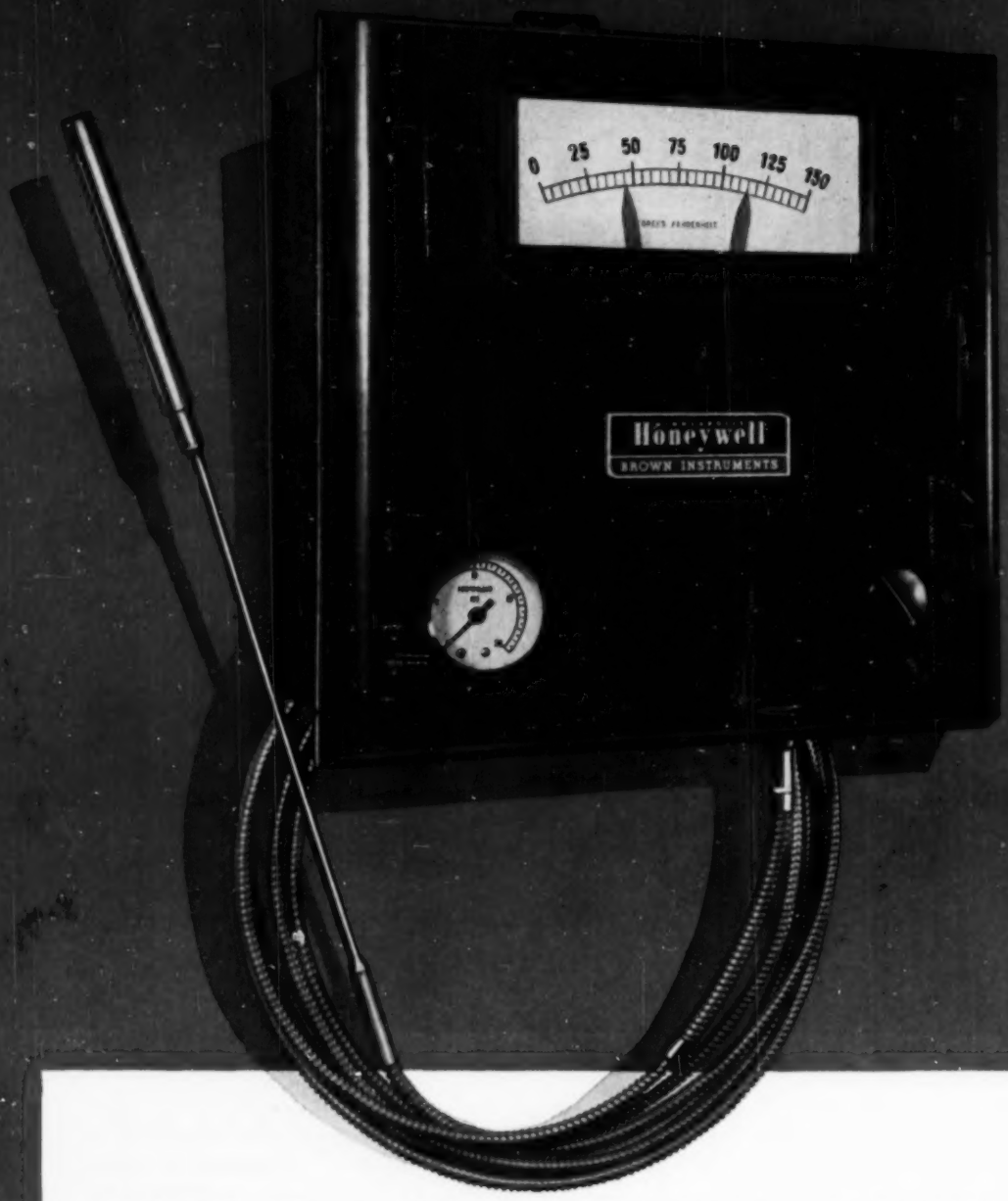

Look at these features of the Model 604P5 Thermometer Controller

GOOD READABILITY:
indicates temperature on 4½" scale.

QUICK CONTROL CHECK:
readily visible red control pointer and black indicating pointer.

CONTROL AIR CHECK:
front-mounted gauge indicates air pressure to control valve.

VARIETY OF CONTROL:
direct or reverse acting pneumatic control —either on-off or proportional action.

SELECTION OF RANGES:
23 different temperature ranges, up to 1000°F., in Fahrenheit and Centigrade calibrations, for vapor and mercury bulb systems.

COMPACT DESIGN:
die cast aluminum case 11" x 11", 4" deep; gasketed black plastic cover; practically splashproof. Interchangeable flush or surface mounting on panels of any thickness.

SIMPLE SETTING:
external knob for adjusting control point

A new, low-cost temperature controller *from Honeywell*

MANY processes which now use manual control can utilize the advantages of automatic operation at unusually low cost—by employing the new Brown Pneumatic Thermometer Controller.

For the scores of ovens, vats, dryers and similar equipment which need only temperature indication and relatively simple control, this new instrument affords excellent control performance. It's fast, accurate . . . and simple in design. It takes so little space that it can fit readily into existing equipment or on panels.

Instrument and thermal system are complete in one package. The set point is easily adjusted by means of an external knob. The selection of control actions, ranges and types of thermometer bulbs covers literally hundreds of control applications throughout industry.

In spite of its low price, this controller is a precision-built instrument which incorporates many of the long-lasting, high-quality components used in other Honeywell products. And it's backed by Honeywell's nationwide service organization, strategically located in more than 90 principal cities of the United States and Canada.

Our local sales engineer will be glad to discuss how this new controller can be applied to your own temperature problems. Call him today . . . he is as near as your phone.

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MARGINAL NOTES

News of Books of Interest to Chemical Engineers

A Timely Summary

Fluorine and Its Compounds. R. N. Haszeldine and A. G. Sharpe. John Wiley & Sons, New York (1952), 152 pp. $1.75.

Reviewed by T. J. Brice, Central Research Department, Minnesota Mining & Manufacturing Co., St. Paul, Minn.

Only in recent years have fluorine chemistry and technology emerged as separate and important activities. The timeliness of the book is thus evident. The authors are two young men who have become well known as a result of their recent researches in this field in England.

The announced purpose of the book is to provide a balanced review of the properties of both inorganic and organic fluorine compounds; special emphasis has been placed on the relation between structure and properties of inorganic fluorides and of the influence of fluorine on the properties and reactivities of organic compounds.

The result is a clear and readable book that provides the basic principles of fluorine chemistry and, despite its space limitations, includes surprisingly detailed information on many topics. The book is divided into two portions. The first half is concerned with inorganic fluorides, the second half with organic fluorides. The scope of the review is indicated by the four chapter headings: Fluorine, Hydrogen Fluoride, Inorganic Compounds of Fluorine, and Organic Compounds of Fluorine.

The book can well serve as an introduction to fluorine chemistry and properties to those who feel they would like to be acquainted with this new field; it is a handy and useful summary.

Looking Backward and . . . Forward

Centennial of Engineering 1852-1952. Edited by Lenox R. Lohr. Published by Centennial of Engineering, 1952, Inc., New York (1952), 1080 pp. $10.00.

The progress of engineering in its lifetime of 100 years, combined with the hundredth anniversary of the formation of the first national engineering society in the United States, namely, the American Society of Civil Engineers, was the purpose behind the publication of this volume, Centennial of Engineering. This voluminous work is a record of accomplishment, a story of the centennial celebration in Chicago in September, 1952, and a reprinting of more than 100 papers delivered at the Convocation there.

This volume is arranged in two books: Book I, The Centennial Celebration, tells how the idea of the centennial took form, the philosophy back of the celebration, the events of the meeting, such as the Centennial Awards luncheon, Centennial evening party, the account of the Commemorative Postage Stamp, International Day at the Museum of Science and Industry, and finally the musical presentation "Adam to Atom," depicting the contributions of invention and technology.

An appendix for this book includes names of officers of the Centennial Corp., directors of the Centennial Corp., sponsors and participating societies, and trustees of the Museum of Science and Industry.

Book II, called The Convocation, comprises twelve sections of 900 pages devoted to the full text of more than 100 papers delivered by outstanding engineering leaders in such fields as chemical industries, education, transportation, mineral industries, tools, communications, energy, health and human engineering, and urbanization. A separate Table of Contents is provided for each section with titles of papers and authors, and there is an Index.

This work is not just a souvenir of a great event to be placed on the shelf of an engineer's library, but rather is it a repository of information and a memento of the indomitable courage of past performers in the field of engineering through whose efforts life was made generally better and fuller. Again, this story solidifies one's belief in the aspirations of today's engineer, who in Mr. Kettering's opinion, as expressed in the Foreword, has scarcely scratched the surface.

—H.R.G.

Another "Bible" for the Atomic Specialist

Experimental Nuclear Physics, Vol. I. E. Segre (Editor). John Wiley & Sons, Inc., New York (1953), 789 pp. $15.00.

Reviewed by Lawrence C. Widdoes, Monsanto Chemical Co., St. Louis, Mo.

Written primarily for the advanced student and researcher in the field of nuclear and atomic physics, this volume will also interest the engineer engaged in similar or related fields.

The book is especially broad in its coverage of the subjects treated. In most cases a brief historical background is followed by a comprehensive treatment of the physical principles and the mathematical derivations. This in turn is followed by an up-to-date explanation of the instruments used. The 790-page book covers in this manner the detection of the fundamental particles of atomic and nuclear physics, the passage of radiation through matter, nuclear moments and statistics, nuclear two-body problems and elements of nuclear structure, charged particle dynamics and optics, relative isotopic abundance of the elements, and atomic masses. Each section is written by an outstanding specialist, and complete references to the original literature follow each chapter.

If volumes II and III cover subjects, such as measurement of nuclear cross sections, danger coefficients, and the use of exponential piles in similar style, the three volumes will indeed furnish a valuable referer.ce work for the specialist.

A Ring Around a Compound

The Furans. A.C.S. Monograph No. 119. A. P. Dunlop and F. N. Peters. Reinhold Publishing Corp., New York (1953). 867 pp. $18.00.

Reviewed by Paul Bruins, Professor, Chemical Engineering, Polytechnic Institute of Brooklyn, Brooklyn, N. Y.

The commercial production of furfural beginning in 1922 has stimulated a tremendous amount of research in the field of furan chemistry. This mono-

(*Continued on page* 31)

...A CONSTANTLY IMPROVING LINE

Specify "National" Carbon and Graphite and "Karbate" Impervious Graphite Equipment for Processing, Conveying and Storing Corrosive Fluids.

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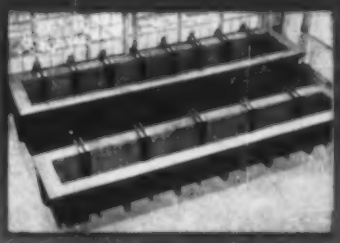

Accepted material for lining tanks, towers, digesters and other vessels containing corrosive chemicals. Catalog Section S-6210.

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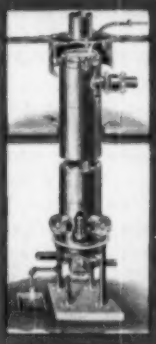

Versatile, standard equipment for hydrogen chloride synthesis. Burns most gases. Simple to operation. Catalog Section S-7530.

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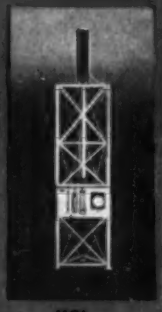

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For absorption, fractionation and scrubbing. Easily erected from standard monolithic sections and components. Catalog Section S-7550.

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For heating and agitating corrosive solutions by direct injection of steam. Catalog Section S-7300.

Fluid-Coking Process Developed by Standard Oil

Development of a new fluid-coking process, the latest adaptation of the fluidized-solids technique, was announced recently by E. V. Murphree, president of Standard Oil Development Co. A further development of fluid catalytic cracking, this process, according to Standard Oil officials, offers an improved, economical technique for reducing yields of residual products from crude oils and for exploiting reserves of low-quality crude oil which heretofore could not be economically marketed.

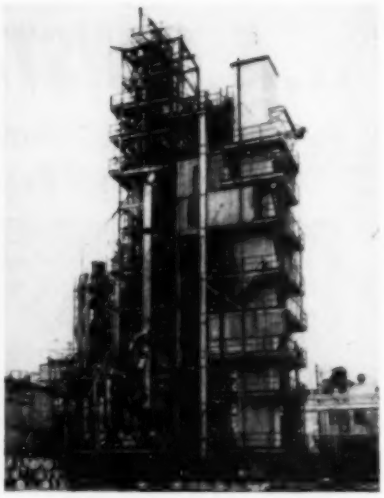
A principal advantage of the fluid-coking process is the reduction of residual fuels, for which the market has decreased, and the yield of light products (gasoline and home-heating oil) from crude oil.

Equipment requirements for fluid coking are more independent of the type of feed than are those for some of the older coking processes. Residual oils with initial boiling as low as 600° to 700° F. can be handled, as can vacuum residua with initial points of 1,100° F. or higher. Feed stocks with gravities as low as 1.8° A.P.I. or with Conradson carbons as high as 35 per cent have been processed. Periodic changes in feed stocks therefore can be handled without difficulty, Standard Oil engineers explained.

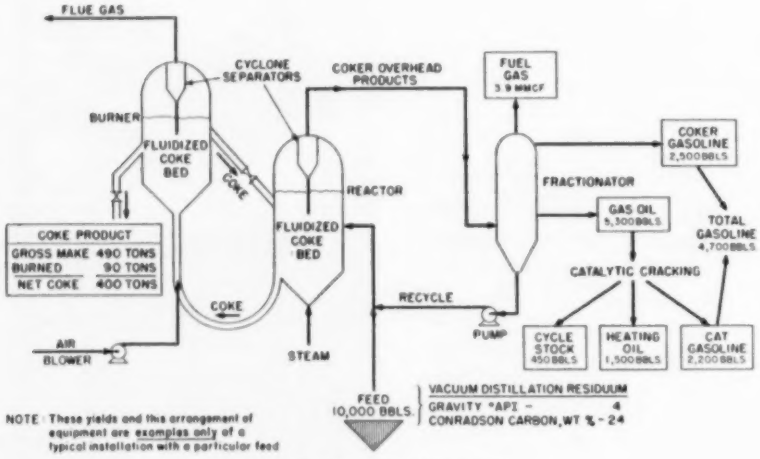
The accompanying flow sheet illustrates how the fluid-coking process might be adapted for a typical refinery. The unit shown consists essentially of a reaction and a burner vessel. The crude-oil residuum to be coked is injected into a fluidized bed of coke particles in the reaction vessel with a uniform temperature of 950° to 1,050° F. In the reactor the feed stock is almost completely converted into overhead vapor and coke. The coke is deposited on the coke particles already in the fluidized bed, and the vapor products are carried overhead through a cyclone separator, which removes most of the entrained coke and returns it to the reaction zone. The overhead product then passes to conventional separation equipment such as fractionation towers, etc. A small amount of recycle bottoms is returned to the reactor.

In this continuous process the heat for carrying out the fluid-coking is generated in the burner vessel. No external furnace is usually required. A stream of coke is transferred like a fluid through a standpipe-riser system to the burner vessel. Air is supplied to burn enough of the coke (about ⅕ of that produced) to provide heat, and the hot coke carries heat back to the reactor, completing the continuous circuit.

The net coke produced in the process is withdrawn continuously to maintain the proper inventory in the system. In the case shown in the flow sheet 490 tons of coke is produced from 10,000 bbl. of feed stock, but 90 tons of this would be consumed unless an extraneous fuel were used in the burner.



Originally the proving ground for fluid catalytic cracking, this 100-bbl./day pilot plant at the Esso Laboratories in Baton Rouge, La., was modified to demonstrate the operability of Standard Oil Development's new fluid-coking process.



Flow sheet for fluid-coking process.

Ten thousand barrels of 4° A.P.I. gravity vacuum distillation residuum can be converted to 2,500 bbl. of coker gasoline and 5,300 bbl. of gas oil, which in turn can be catalytically cracked to give, for instance, 2,200 bbl. of gasoline and 1,500 bbl. of heating oil. A total of 6,200 bbl. of valuable light products can be made from 10,000 bbl. of low-value feed stock. Another major benefit of the process is that the 4,000 to 6,000 bbl. of distillate oils that normally must be blended with 10,000 bbl. of such a residuum to give a fluid marketable fuel oil are no longer required. The coke produced from fluid coking is suitable for refinery fuel or for fuel in power-plant boilers, although with some feed stocks the coke might have more value, for example as a factor in the production of carbon electrodes for aluminum manufacture.

Begun about four years ago, the development of fluid-coking progressed rapidly to the pilot-plant scale, a company official explained. A plant with a capacity of 100 bbl./day previously used to develop fluid catalytic cracking at the Esso Laboratories in Baton Rouge, La., was modified and has been operating as a fluid coker for the past year. Now ready for commercial-scale application, the process will be installed soon on three locations, a 3,000 bbl./day plant at Billings, Mont.; a 10,000 bbl. unit at Baltimore; and a 20,000 bbl. plant at Baton Rouge. The process will also be available to the industry on a royalty basis.

(*More News on page* 48)

Name Your Flow Metering Problem . . .

Here's the Solution!

Difficult metering jobs — formerly so "impossible" to maintain as to be abandoned or not even attempted — have proved to be successful routine operations with the Foxboro d/p Cell. Here are just a few typical examples:

CORROSION

Corrosive fluids such as fuming nitric acid, SO_2 and dry Cl_2 can be handled without seals or purges, by the all-316 stainless steel construction of the d/p Cell. For materials which attack 316 stainless steel, the negligible displacement (3cc) of the d/p Cell permits use of liquid seals without seal pots, or loss of seal fluid due to pumping. Successful installations include mercury sealing of anhydrous HF, and oil sealing of 30% H_2SO_4.

FREEZING

Flowing fluids that freeze at ambient temperatures can be metered without difficulty by the d/p Cell. Its unique construction permits simple steam tracing or electric heating of the cell body and meter leads to maintain fluid conditions. Accurate metering of naphthalene for ratio flow control with oxygen in the production of phthalic anhydride is typical of numerous services for which d/p Cells are currently employed.

SLURRIES

Most slurries can be metered directly in the d/p Cell. For the more concentrated types, a small liquid purge (one liter per hour) maintains the cell free of deposit. Lime and phosphate slurries and 4½% paper pulp are typical of many materials now being handled.

COAGULATION

Plugging of meter lines by materials that coagulate or polymerize is held to a minimum by the small displacement of the d/p Cell. On synthetic rubber latex, for example, reliable metering has been obtained; production downtime for instrument maintenance has been practically eliminated; and routine clean-out time has been reduced 87%! (Details given in Rubber Reserve report available from Foxboro.)

For your simple, "everyday" jobs of metering steam, water, hydrocarbon and other common fluids, the d/p Cell offers equally important advantages. Its light weight and simple piping make installation easy and economical . . . its sturdy, simple design practically eliminates maintenance. Write for detailed information on the d/p Cell or its application to your particular problem.

THE FOXBORO COMPANY, 939 NEPONSET AVE., FOXBORO, MASS., U.S.A.

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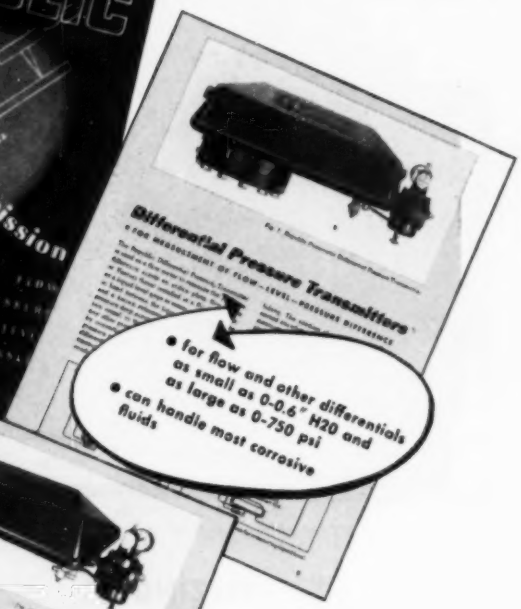
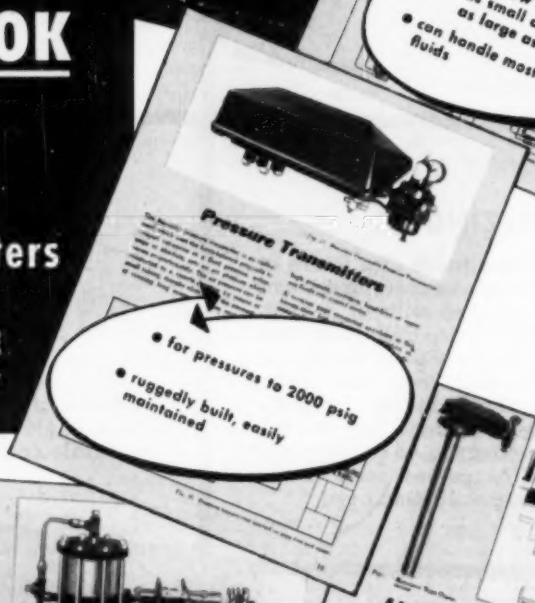
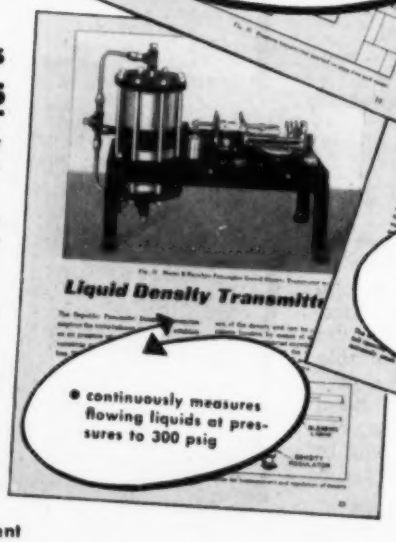

Differential Pressure Transmitters
• for flow and other differentials as small as 0-0.6" H20 and as large as 0-750 psi
• can handle most corrosive fluids





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MARGINAL NOTES

(*Continued from page 26*)

graph is an encyclopedic attempt to report this research through December, 1950.

The book is divided in two parts: Part I is a comprehensive review of furan chemistry, and Part II is concerned with furfural, including properties, production, industrial uses and derivatives.

An appendix lists by number and title the furan resin patents.

A random check of numerous references, familiar to this reviewer, demonstrated to his satisfaction the thoroughness of the literature review. Because of the voluminous details in the literature, it would frequently be necessary to go to the original references for complete information. This is particularly true with respect to industrial applications. There are separate chapters dealing with the large industrial uses of furfural, such as its use in the making of chemical intermediates for the manufacture of nylon, its solvent applications, and resins derived from either furfural or furfuryl alcohol.

This book should prove to be a valuable addition to any library and an idea originator to anyone working in the field of organic chemicals.

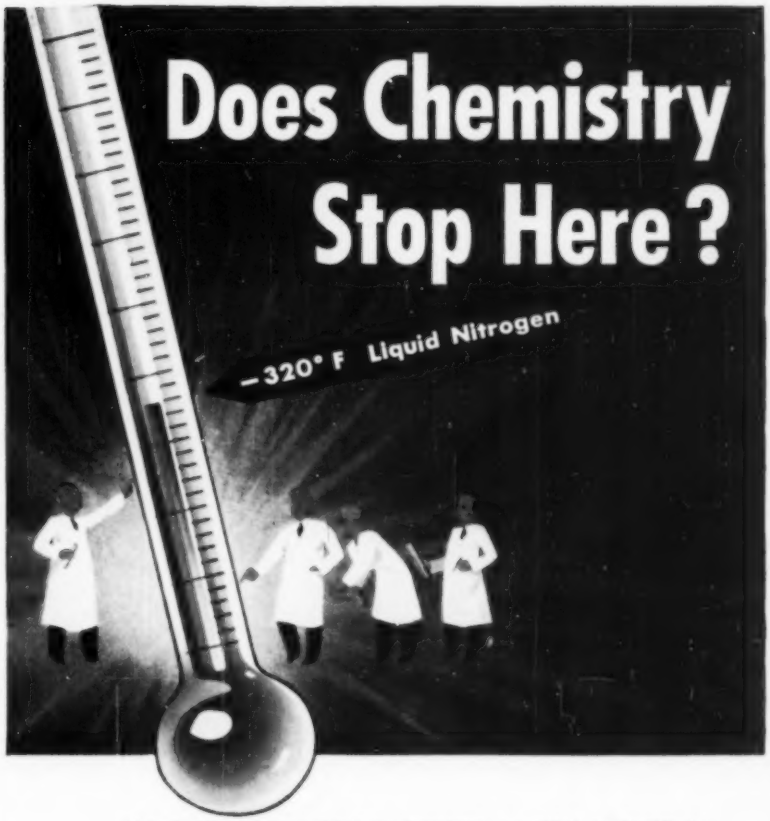
Theorems Summarized

Advanced Statistical Methods in Biometric Research, C. R. Rao. John Wiley & Sons, Inc., New York (1952), xvii + 390 pp. $7.50.

Reviewed by Stuart T. Hadden, Socony-Vacuum Laboratories, Paulsboro, N. J.

This book is a concise presentation of a considerable amount of modern advanced statistical methods and relates to biometric research only in that the examples are from this source. The author's objectives in writing the book were ". . . first, to provide a theoretical groundwork . . . and second, to illustrate computational procedures by working out a number of problems in full . . . ." With some reservations, the author is successful in gaining his goals. His style of writing is difficult to read as it is heavy and complex. Conditions necessary for theorems to hold are straggled through the preceding text. The worked examples are usually clearly explained, however, the lack of generality of a method is not always pointed out. For example, the procedure given (p. 103) for the least square evaluation of the constants A, a, b, and c in an equation

(*Continued on page 69*)



Normally when we think of chemistry, we think of chemical activity at room temperature and above. Yet it is possible that important anomalous behavior will appear in a very small temperature interval . . . perhaps near Absolute Zero.

Although research near absolute zero (−460° F) is relatively new, it is contributing daily to the metallurgists' understanding of the properties of metals . . . And physicists have already discovered promising low-temperature phenomena, such as superconductivity, and are now looking toward their practical application.

At present, low-temperature chemistry is mostly an interesting combination of words. But this is changing. Chemicals which are extremely reactive at ambient temperature may conceivably be stabilized at low temperature. Knowledge of what happens at extreme low temperature can be of particular value to chemists as a key to the explanation of high-temperature reactions.

Today, facilities for extreme low temperature are part of a well-equipped laboratory for virtually all fields of research. Write for descriptions of low-temperature equipment and applications — Bulletin CEP 22-5.

ADL Mechanical Division

ARTHUR D. LITTLE, Inc.

MECHANICAL DIVISION

30 MEMORIAL DRIVE, CAMBRIDGE 42, MASS.

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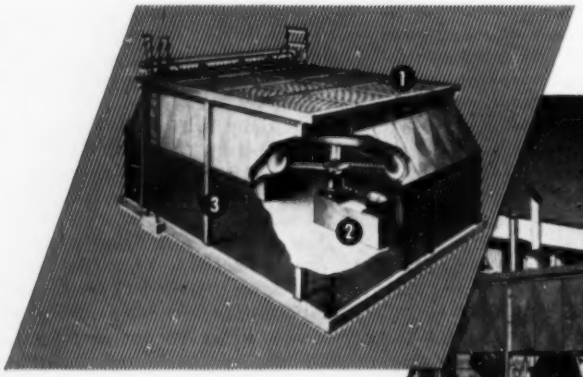

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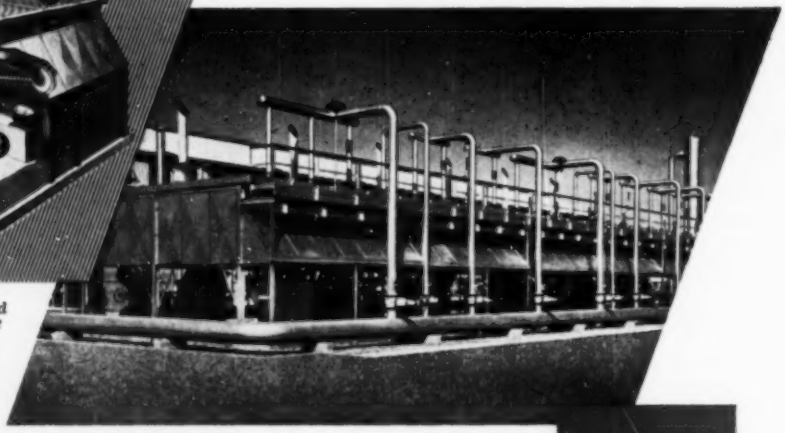

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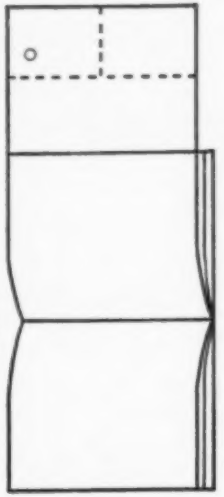

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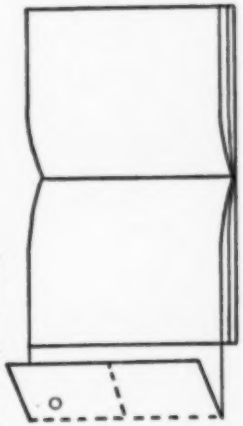

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Complete solvent recovery systems to fit specific requirements. Booklet.
Carbide & Carbon Chemicals Co.

3R **Vibrex Packers**
Vibrating motion packs materials quickly and densely. Catalog No. 801.
B. F. Gump Co.

4L **Seals for Chemical Piping**
Chemiseal expansion joints and flexible couplings made of Teflon. Bulletin FC-952.
United States Gasket Co.

5A **Sulphur Recovery Plant**
Removal of hydrogen sulphide from the sour gas by the Girbotol process.
The Girdler Co.

6A **Double Motion Agitator**
Mixing vessels for processing heavy viscous materials.
Struthers Wells Corp.

7A **Chlorine for Water Purification**
Graphite anodes for the electrolytic industry.
Great Lakes Carbon Corp., Electrode Div.

8L **Distillation Columns**
Design and fabrication. 85-ft. example illustrated.
Badger Manufacturing Co.

9A **Compound Vacuum Pumps**
Built in four sizes, 2-, 5-, 15- and 46-cu.ft./min. displacements. Bulletin V-51B.
Kinney Mfg. Co.

10L **Acid and Chemical Pumps**
Selected to resist the corrosive and abrasive action of the liquid pumped. Bulletin 203-6.
Lawrence Pumps, Inc.

11A **Louisville Dryer**
Rotary coolers and rotary steam-tube dryers.
Louisville Drying Machinery Unit, General American Transportation Corp.

12L **Stainless Steel Vapor Condensers**
Standardized vapor condensers. Coupon for literature.
Doyle & Roth Mfg. Co., Inc.

13A **Tubing**
Alloy tubing for pulp and paper, textile, photographic, industries.
Babcock & Wilcox Co., Tubular Products Div.

14A **Angle Valves**
12-in. iron body valves for steam, water, oil and gas. Catalog.
Crane Co.

15A **Heavy Duty Filter**
60-sec. opening, sized from 100- to 2000-sq. ft. filtering area.
Sparkler Manufacturing Co.

16A **Glass-to-Steel Equipment**
Glass-lined vessels for both pilot plant operations and full-scale production. Bulletin 902-L-2.
The Pfaudler Co.

454A **Winterized Resin Kettle**
Cold-climate Turbo-Mixer polymerizer for continuous outdoor operation.
Turbo-Mixer Div., General American Transportation Corp.

17A **Tower Packing**
Intalox saddles, Raschig rings, lessing rings, cross-partition rings, and spiral rings.
U. S. Stoneware Co.

18A **Uranium Production Center**
Master plant to produce highly pure uranium metal.
Catalytic Construction Co.

21A **Large-Capacity Filters**
Vertical and horizontal pressure-leaf filters from 20 to 1500 sq. ft.
Niagara Filter Div.

22L **Oil Reclaimer**
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The Hilliard Corp.

23A **Heat-Transfer Medium**
Dowtherm for the chemical, petroleum, paint, food and other process industries.
Dow Chemical Co.

24A **Temperature Controller**
Brown automatic pneumatic thermometer controller.
Minneapolis-Honeywell Regulator Co.

27A **Impervious Graphite**
Processing, conveying and storing corrosive fluids in Karbate impervious graphite equipment. Catalogs.
National Carbon Co.

29A **Flow Metering**
Use of a d/p cell for measurement of fluid flow under adverse conditions.
The Foxboro Co.

30A **Pneumatic Transmitters**
For measuring flow, pressure, level, density. Data Book 1004.
Republic Flow Meters Co.

31R **Collins Helium Cryostat**
For liquefying helium. Maintains a test chamber from normal room temperature to within two degrees of absolute zero.
Arthur D. Little, Inc.

32A **Heat Exchangers**
Fin-fan air-cooled heat exchangers for cooling where final fluid temperature is higher than dry bulb air temperature.
The Fluor Corp., Ltd.

41A **Spray Drying**
Spray dryer producing a sterile dextran product.
Bowen Engineering, Inc.

42A **Pyrex Glass Pipe**
How Hydrocarbon Chemicals, Inc., uses glass pipe.
Corning Glass Works

45A **Pilot Filter Stations**
A stainless steel filter with multiple-cake-washing, vapor-tight hood, and roller discharge.
The Eimco Corp.

46T **Polyethylene Pumps**
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Vanton Pump Corp.

46B **Spray Nozzles**
Catalogs on spray nozzles.
Spraying Systems Co.

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C. G. Sargent's Sons Corp.

48L **Mixers**
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49A **Rate Totalizer**
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Fischer & Porter Co.

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Techniques and equipment for wet processing. Bulletin.
The Dorr Co.

51R **Alloy Castings**
Special high alloy castings for the process industries.
The Duraloy Co.

52L **Permanite Equipment**
Furfural alcohol resin equipment reinforced with Fibreglas, for handling corrosives. Bulletins.
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Pumps with discharge pressures from 300 to 15,000 lb./sq.in.
The Aldrich Pump Co.

56L **Haveg Pump Parts**
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Haveg Corp.

57A **Conkey Filters**
Rotary leaf-pressure filters, dewaterers, and sludge filters.
Process Equipment Division, General American Transportation Corp.

58L **Antifoam**
Defoams cottonseed oil, fermenting wheat, neoprene latex, paper sizing, and vat dies. Coupon for free sample.
Dow Corning Corp.

59A **Corrosion-Resistant Valving**
Teflon diaphragms for Hills-McCanna Saunders patent valves.
Hills-McCanna Co.

60L **Corrosive Proof Ducts**
Resin-bonded glass fiber ducts for corrosive fumes ranging from —60° F. to 280° F.
The Chemical Corp.

61A **Magnetic Traps**
For prevention of machinery damage, product contamination, and production tie-ups.
The International Nickel Co., Inc.

62L **Photochemical Equipment**
For continuous flow, batch or recycling processes using photochemical processes. Literature.
Hanovia Chemical & Mfg. Co.

63A **Amberlite Ion Exchange**
Cation exchange resin absorbs copper salt solutions.
Rohm & Haas Co.

64L **Centrifuges for Crystal Dehydration**
Capacities range up to 8 tons/hr. Bulletins.
The Sharples Corp.

65A **Celite Filtration**
Removes fine suspended solids.
Johns-Manville

66L **Chemical Exposition**
24th Exposition of Chemical Industries, Nov. 30 to Dec. 5. Convention Hall, Philadelphia. Application forms for hotel accommodations.
Chemical Industries Exposition

67R **Chemical Processing Mixers**
To mix and knead materials for dry powders and light fluids to stiff plastics.
Baker Perkins, Inc.

69R **Metex Mist Eliminators**
Separators made from layers of knitted wire mesh. Catalog.
Metal Textile Corp.

70T **Rubber Plasticizer**
Plasticizer oil for rubber compounding. Compatible with GRS, neoprene, and buna N type rubbers.
Pan American Refining Corp.

70B **Filters**
Filters to recover solids, clarify, purify, wash or extract, and steam, melt or redissolve. Catalog.
T. Shriver & Co., Inc.

71R **Yorkmesh Demisters**
Entrainment separators—mist eliminators made of finely woven wire. Catalog.
Otto H. York Co., Inc.

73T **Grinders, Crushers**
For small laboratory mills to high tonnage mills. Literature.
American Pulverizer Co.

73B **Pilot Plants to Processing Equipment**
Manufacture of full range of chemical processing equipment.
Artisan Metal Products, Inc.

74T **Poro-Stone Filters**
A package plant for special and standard filtering problems. Model for continuous filtration molten phosphorous. Bulletin.
R. P. Adams Co., Inc.

74LC **Tankometer**
Liquid-level gauges for all purposes. Bulletins.
Uehling Instrument Co.

74BL **Portable Depth Gauge**
Two portable standard tank gauges in stock.
Aerco Industries

75R **Bamag Nitric Acid Process**
Ammonia conversion at atmospheric pressure.
General Industrial Development Corp.

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Nylon, Orlon, Dynel, or Vinyon-n filters. Free fabric selector chart.
Filtration Engineers, Inc.

77T **Steam Traps**
For heat, power, process; sizes ¼ in. to 2 in.; pressures to 250 lb. Bulletin.
W. H. Nicholson & Co.

77BL **Mechanical and Process Equipment**
Complete engineering service. Catalogue.
Engineering Corp. of America

77BR **Metals Handbook**
Written by more than 500 scientists and engineers, 1332 pages.
American Society for Metals

80TL **Temperature Switch**
Two-switch temperature control, explosion proof. Range from —300° F. to +1800° F. Catalog.
Burling Instrument Co.

81R **Jet Evactors**
Evactors and barometric condensers to simulate high altitude conditions in testing jet-plane engines.
Croll-Reynolds Co., Inc.

IBC **Controlled Volume Pumps**
Air-powered or motor-driven units with capacity range of 3 to 3,200 ml./hr.
Milton Roy Co.

OBC **Lightnin Mixers**
16 speeds with one gearbox. 1 to 500 hp. sizes.
Mixing Equipment Co., Inc.

BULLETINS

1 **Motor and Control Catalog.** Westinghouse Electric Corp. loose-leaf catalog of motors and controls for chemical-processing industries. Tabbed sections.

2 **Liquefied-Gas Compressors.** Ingersoll-Rand compressors for liquefied gas transfer discussed in illustrated bulletin. Construction described in sectional view. Operational and construction features, and unloading cycle pictured.

3 **Reciprocating Pump Manual.** Warren Steam Pump Co., Inc. manual on installation and maintenance of pumps, plus general engineering information for operating engineers.

4 **Electro-Conductivity Analyzer.** For analysis of gases and vapors which ionize in water or when decomposed by heat. Engineered to individual needs. Sensitive to small quantities of contaminants. Davis Emergency Equipment Co., Inc.

5 **Plug Valves.** Duriron Co., Inc. bulletin on corrosion-resistant plug valves. Screw-end sizes ½ through 2 in.; flanged end 1 through 6 in. Tables, dimensions, diagrams.

6 **Chlor-O-Feeder.** All purpose, positive displacement diaphragm pump heavy-duty midget Chlor-O-Feeder from %Proportioneers, Inc.%. Construction details, performance curves, etc.

7 **Nitrogen and Air Filters.** All-metal filters for liquids, solids, gases; strip water from liquids. Booklet from Permanent Filter Corp. shows photographs of each type with engineering details of application and performance.

8 **Controllers.** Time-cycle controls from Bristol Co. Bulletin illustrates available models, describes operating principle. Used in most manufacturing operations.

9 **Check Valves.** Edward Valves, Inc. catalog on pressure-seal stop, non-return check valves in 600 to 2500 lb. pressure class. Construction, dimensional details, schematic drawings.

10 **Karbate Pipe and Fittings.** National Carbon Co. catalog section on Karbate impervious graphite pipe and fittings. Threading and serrating tools, assembled fittings, couplings, accessories described and illustrated. Useful for design engineers.

11 **Steel-Plate Fabrication.** Leaflet from Continental Boiler & Sheet Iron Works on experience, engineering, plant facilities, and special services available in steel-plate fabrication.

12 **Coupling Units.** Ever-Tite Coupling Co., Inc. brochure on standard quick coupling units. Made of bronze, aluminum, stainless, carbon steel.

14 **Stainless Pipe and Tubing.** Welded or seamless stainless pipe or tubing, variety of fittings available from A. B. Murray Co. Folder gives schedules on various types and sizes.

15 **Gate Valves.** Two types of forged-steel gate valves from Chapman Valve Mfg. Co. Sizes ¼ to 2 in. Pressure ratings, features, materials of construction.

16 **Resin Equipment.** Bulletin from Blaw-Knox Co. on design and equipment of resin plants; pilot to full-scale units. Instrumentation, agitation, methods of heating and cooling, etc.

17 **Hardinge Mills.** Line of grinding mills and application contained in bulletin from Hardinge Co., Inc. Cutaway views, list of successfully ground materials. Includes conical, rod, cylindrical tube, batch and tricone mills.

18 **Turbine Generators.** Westinghouse Electric Corp. turbine-generators for industrial use. Descriptions of various types, illustrations, pertinent data.

19 **Process Plant Equipment.** Bulletin from Acme Coppersmithing & Machine Co. on engineering facilities. Also equipment for distillation, solvent recovery, evaporation, spray dryers.

20 **Centrifugals.** High-speed centrifugals for chemical and process industries from Fletcher Works. Materials of construction, schematic drawings, dimensions, all pertinent information. Variety of types and sizes.

21 **Control Valve Handbook.** Design engineers handbook on control valves in catalog form. Kieley & Mueller, Inc. Sixteen sizes, range ½ to 20 in. in thirteen types. Variety materials and modifications.

22 **Acid-Proof Construction.** Ralph V. Rulon, Inc. construction brochure discusses uses of acid-resisting asphalt mastic. Also acid-proof brick construction, bituminous coatings and special products.

23 **Materials Handling.** Titled "Facts About Materials Handling," a brochure from Clark Equipment Co. on basic facts about fork-lift trucks and industrial towing tractors.

24 25 **Deaerators.** From American Water Softener Co. (24) bulletin on jet-tray deaerators (25) on spray-atomizing type. Both give schematic views, functions, outstanding features, design, application, construction.

26 **Spiral Conveyers.** Spiral conveyors and fittings by Jeffrey Mfg. Co. Illustrated catalog gives engineering instructions, tables of dimensions, capacities, standard lengths, other data.

27 **Displacement Pump.** A bronze impeller, positive-displacement pump from Eco Engineering Co. Features positive displacement delivery, precision machined, sintered bronze powder-metal impellers acting like oilless bearings. Self-priming in low temperatures. Oil temperatures to 500° F.

28 **Cork Insulation.** Bulletin on cork insulation from Witco Chemical Co. Cold application, fluid-type insulating filler of cork and asbestos with bituminous base. Good adhesive, waterproof and corrosion-resistant qualities.

29 **Fan Installation.** Binder of catalog and technical data sheets from Chelsea Fan & Blower Co., Inc. for use by engineers, architects, etc. to aid in selection and installation of ventilating and exhaust fans.

30 31 **Control Equipment Manual.** (30) Allis-Chalmers Mfg. Co. manual gives recommendations for overcoming difficulties with electrical control devices. Includes trouble-shooting chart. (31) Bulletin on motor starters. Operation, and types of enclosures given. All starters equipped with thermal overload protection devices and magnetic starter for low-voltage protection or release.

32 **Variable-Speed Motor.** Bulletin from U. S. Electrical Motors, Inc. on varidrive motors. Equipped with micro-speed control, asbestos-protected windings. One-piece Varibelt transmits power, absorbs load shocks and vibration.

33 **Hydrodesulfurization Process.** From Lummus Co. report on Shell's hydrodesulfurization process for which it is building first unit at Stanlow, England.

34 **Solenoids.** For handling liquids and gases by remote control, solenoid-operated valves. Catalog from Automatic Switch Co. covers explosion-proof trip, pilot and shut-off valves; applications and diagrams.

35 **Fire Protection.** Automatic Sprinkler Corp. of America brochure on "A, B, C, of Fire Protection," covers all phases of subject and systems available.

36 **Laboratory Equipment.** Catalog from Scientific Glass Apparatus Co., Inc. Featured are new industrial balances, several polyethylene aids, duplex heater, penetrometer, etc.

37 **Temperature-Humidity Chambers.** Uniform wet- and dry-bulb temperatures maintained by Tenney Engineering, Inc. chambers. Stainless steel, insulated, 2-in. sidewall port for electrical leads. Meets Government specifications.

38 **Controllers.** Process measurement and control in catalog from Gotham Instruments Division of American Machine and Metals, Inc. Control units, proportional band, pilot relays, tables of dimensions and ranges.

39 **Flexible Hose Data.** Comprehensive catalog from Titeflex, Inc. for use as handbook by design engineers. Gives charts on frictional losses vs. flow rates in flexible hose.

40 **Volume Control Pumps.** Reciprocating, positive displacement pumps deliver controlled volume of liquid. Capacities 45 gal./min.; others 3 ml./hr. Pressures to 25,000 lb./sq. in. Selection tables, capacity adjustments, applications. Milton Roy Co.

41 **Process Equipment.** Design and manufacture of specialized equipment for processing, plant operation, etc., in brochure. L. O. Koven & Bro., Inc. Available services, facilities, and types of products.

42 **Microphotometers.** Two microphotometers — recording and spotting — from Leeds & Northrup Co., illustrated and described in catalog.

43 **Renting Bin Feeders.** Available on a rental basis, pilot-plant units of Com-Bin feeders from Pulva Corp. Handles filter cake, centrifuge cake, products containing moisture and oil, dry solids. Capacity 2⅛ cu. ft.

44 **Industrial Fuel Systems.** Industrial fuel burning system by York-Shipley, Inc. Rotary burner, special mountings, combustion chambers, controls, and control panels, plus accessories.

45 **Couplers and Nipples.** Snap-Tite, Inc. line of quick connect - disconnect couplers provide 80% flow. Sizes ¼ to 8 in. and larger. Handle air, water, oil, gas, many chemicals. Catalog.

46 **Nordstrom Valve Lubrication.** Describing lubricant, lubricant fittings, and methods, bulletin from Rockwell Mfg. Co. For Nordstrom valves. Includes bulk and gun tube, also stick lubricants. Illustrated outline of three functions of lubricant in valve.

47 **Titrilog Recorder.** For rent or sale Consolidated Engineering Corp's Titrilog; continuous monitor-recorder of sulfur-compound concentrations. Typical recording, schematic drawing, other data and functions shown.

48 **Potentiometer.** Electronic pryometer controller for temperature and process control. Signal lights indicate temperature. Accuracy to ¼ of 1% of scale. Thermo Electric Co., Inc.

49 **Variable-Speed Changers.** Technical data sheet from Metron Instrument Co. includes specifications, ratings, operating principle of miniature variable-speed changers. Horsepower, torque, speed ratings, cutaway view.

50 **Wound Round Motors.** Bulletin on ½ to 1000 hp. wound rotor motors from Louis Allis Co. Operating principles, performance curves.

51 **Industrial Signals.** Reference book of sound signals from Benjamin Electric Mfg. Co. Sections on fundamentals of sound, glossary of terms; selection and comparison guides. Specifications and listings of all equipment. For industrial outdoor and hazardous locations.

52 **Construction Problems.** Typical projects and problems of industrial construction arising from war to peacetime production. Robert E. Lamb & Sons, Inc. Discusses modernization, expansion, relocation.

53 54 **Pressure and Vacuum Gauges.** (53) Gauges used to measure vacuums of 10^{-11} mm. of Hg, pressures to 150,000 lb./sq. in. in line of Minneapolis-Honeywell Regulator Co. Catalog illustrated, lists specifications, units available, engineering data. (54) Index of all available literature published 1943 to 1952 in Instrumentation Magazine Index.

55 **Heat Exchangers.** Bulletin on hot water storage heaters and heat exchangers built by Patterson-Kelley Co., Inc. Covers many types. Selection tables.

56 57 **Screw Pumps.** (56) Double external bearing gear and gear hopper pumps from Warren Steam Pump Co., Inc. Included are jacketed, unjacketed, horizontal, and others. (57) Covers standard gear-in-head-type, high-pressure, long-body and standard vertical gear-in-head types.

58 **Spherical Valve.** Spherical valve for all types of blenders, on long and short runs, for handling dry and pasty materials, from General Machine Co. of New Jersey. Eliminates sticking, dusting, or sifting. Leaflet.

59 60 **Pressure Valves, Controls, Transmitters.** (59) Swartwout Co. bulletin on equipment for temperature, pessure, or level control of gases and liquids. Specifications, pertinent data. (60) Bulletin on autronic pressure transmitters. Feature low hysteresis, electric motors, easy adjustment, dustproof case.

61 **Laboratory Equipment.** "What's New for the Laboratory," publication from Scientific Glass Apparatus Co., Inc.

62 **Filters and Pumps.** Loose-leaf binder from Oliver United Filters, Inc. contains literature on all types of filters manufactured. Also diaphragm slurry pumps.

63 **Gauges.** Presenting complete line of gauges, a 70-page catalog from U. S. Gauge, Division of American Machine and Metals, Inc. Information on selection, specifications, construction, sizes, etc.

64 **Screw Pumps.** Bracket-type screw pumps by Sier-Bath Gear and Pump Co., Inc. for use in processing in petroleum, power, and other industries. Advantages, dimensions covered in bulletin. Diagram and cutaway view.

65 **Gas and Electricity.** For establishing new plants American Gas and Electric System illustrated brochure and map of the areas in the states of Michigan, Indiana, Ohio, Pennsylvania, Virginia, West Virginia, Kentucky, Tennessee and North Carolina, their lines serve. Shows natural resources, steam, hydroelectric and other plants, transmission lines, railroads, etc.

66 **Nickels and Alloys.** For production and design engineers, a publications list from International Nickel Co., Inc.

67 **Water Conditioning Plant.** (67) A self-contained unit to chlorinate, coagulate, filter, dealkalize and soften raw water supplies, described and illustrated in Permutit Co. bulletin. (68) Brochure on demineralization, including silica removal by ion exchange.

EQUIPMENT

70 **Hydro Sheave Drive.** Hydraulic power transmission unit for application to electric motors and internal combustion engines of ¾- to 40-hp. range. Twin Disc Clutch Co.

71 **Liquid Level Meter.** Purgerator, a small flowmeter for measuring flows of purge fluids or liquid level gauging from Fischer & Porter Co. Pressures to 300 lb./sq. in.; various models each with 10:1 range; flow ranges 0.05 cc./min. and 0.65 gal./min. water. Only 4 13/16 in. long.

72 **Rating-Recording Spectrophotometer.** Operable on single- or double-beam rating-recording infrared spectrophotometer produced by Perkin-Elmer Corp. 1 to 40 μ.

73 **Safety Unloading Platform.** A dome-unloading device for tank cars by Nichols Engineering Co. discussed at length in booklet containing engineering drawings. Features operator safety.

74 **Temperature Regulator.** New self-operating temperature regulators by Farris Stacon Corp. Direct or reverse action, tight shut-off, overload protection, easy dial adjustment. For hot-water heaters, tanks, kettles, etc. Wide temperature range.

75 **Magnet Chart.** Single page, illustrated chart from Eriez Mfg. Co. on "What Makes a Magnet?" Explains potential magnetic forces found in a ferromagnetic atom.

76 **Valve Multiwall Bags.** Valve-type gussetted multiwall shipping bags known as Kraft-lok from Kraft Bag Corp. Valve-closing device is an integral sleeve.

77 **Transitor Servo Amplifier.** Featuring transitor-magnetic circuitry in a hermetically sealed enclosure, servo amplifier from Industrial Control Co. Operates under high acceleration, low internal heat dissipation, small size.

78 **Fuel Valves.** On-off, bellows-sealed, fuel valve from Minneapolis-Honeywell Regulator Co. Handles flowing mediums as gasoline, water mixtures, alcohol, jet fuels. Screwed ends for sizes 1 through 2 in.; flanged ends 2½ to 3 in. Bronze bellows. Specification sheet.

79 **Decimal Equivalent Decal.** For engineers, designers, draftsmen, etc. convenient time saving decal showing decimal equivalents in 64ths. Available from Meyercord Co.

80 **Multicomponent Analyzer.** For continuous infrared analysis of pilot plant process stream Perkin-Elmer Corp. automatic multicomponent analyzer. Monitors up to six components. Complete cycle time six minutes.

81 **P-V Fittings.** Rigid, nonplasticized polyvinyl chloride threaded I. P. S. molded-pipe fittings. Sizes ¼ to 2 in. Pipe in matching sizes and 10 to 20 ft. lengths may be threaded by using ordinary pipe dies. H. N. Hartwell and Sons, Inc.

82 **Dust Collector.** Self-cleaning cloth screen dust collector announced by Pangborn Corp. Engineering features illustrated. Uses reverse air flow for continuous cleaning.

83 **Silicone Rubber Parts.** Silicone rubber fabricated into molded and extruded shapes of all types. Lee Tire & Rubber Corp.

84 **Dial Thermometers.** Bulletin from Taylor Instrument Companies describes devlopment of 6-in. dial indicators for temperature, pressure and load applications. General information, illustrations, dials and scales available, plus reference material.

85 **Electronic Pyrometer Control.** Introduced by Thermo Electric Co., Inc. automatic thermoelectronic pyrometer controllers for use with iron constantan chromel alumel, platinum thermocouples. Twelve scale ranges from temperatures 0 to 3000° F. Accuracy within ¼ of 1% of scale.

86 **Potentiometer.** Pressure operated potentiometer for barometric range 0 to 15 lb./sq. in. Accuracy 2% of scale; 2 in. diam. X 2.5 in. long. Trans-Sonics, Inc.

87 **Flowmeter.** Link Engineering Co. flowmeter eliminates purging or freezing of instrument lines. Utilizes principle of flow velocity. Long, straight approach not required. For pressures 0 to 3000 lb./sq. in.

88 **High-Temperature Alloys.** Publication of H. M. Harper Co. features nontechnical information on alloys, how made into high-precision fastenings. Discussion of cold heading, other features.

89 **X-Ray Analysis Chart.** Wall chart shows X-ray analysis curve for illium. Available from North American Philips Co., Inc. Shows peaks for molybdenum, tungsten, copper, nickel, cobalt, iron, etc.

90 **Portable Kettle.** Synthetic resin kettle by Brighton Copper Works, Inc. Capacity 250 gal. Special bearing oil seal prevents grease and oil from entering kettle. Adjustable foam breaker.

91 **Jet Pulverizers.** Majac Engineering Co. jet pulverizers for pulverizing limestone, iron oxide, plastics, alumina, etc. Produces pulverized fuel to excess of 90% through 200-mesh screen. Bulletin on technical data, engineering, and operation.

92 **Titanium Tubing.** Superior Tube Co. announces smallest tubing ever drawn from titanium. For experimental work in electrical, electronic and chemical industries. Sizes ⅛ to 1½ in. O.D. Wall thickness 0.004 in. to 0.187 in.

93 **Self-Cleaning Strainer.** Automatic self-cleaning strainer by S. P. Kinney Engineers, Inc. 2-in. to 36-in. pipe-line sizes. Removes fine suspended particles from water.

94 **Crescent Solenoid Valves.** Bulletin on crescent solenoid valves for air, water, light oil; 3-way and 4-way from Barksdale Valves. Pressures 150 or 500 lb./sq. in.; sizes ⅛ to ¾ in.

95 **Line Blind Valves.** Hamer Oil Tool Co. rigid line blind valves for petroleum refineries, process plants. Internal-expansion principle eliminates need for spread of pipe line.

96 **Laboratory Burner.** For simplifying testing reaction of a train of solutions at control tempeatures and pressures a laboratory burner from Submerged Combustion Co. of America, Inc.

97 **Electronic Relay.** Announced by General Electric Co. electronic resistance-sensitive relay. Automatically stops or starts fractional horsepower motor. For liquid-level control, small parts sorting, etc.

98 **Sanitary Pump.** Rotary pump for sanitation, volume control, from Waterous Co. Meets 3A standards. Easily cleaned, self-priming, non-agitating. Features sanitary seals outside pumping chamber.

99 **Fiberglass Tanks.** Laminex Corp. fabricated corrosion-resistant Fiberglass tanks in sizes to 12 ft. long or wide, by 4 ft. depth.

100 **Resonance Spectrometer.** For determination of molecular structures and mixture components Varian Associates high resolution nuclear magnetic resonance spectrometer. Applicable to compounds containing hydrogen or fluorine.

101 **Tube Fittings.** Crawford Fitting Co. Swagelok cap and Swagelok plug, for capping end of tube and plugging unused port of fitting. Requires but 1¼ turns of wrench to provide torque-free, leakproof seal. Illustrated catalog.

102 **Thermo-Regulator.** New with Labline, Inc. rota-set thermoregulator for temperature control in water baths, constant temperature rooms, control circuits, etc.

103 **DC Rectifier Welder.** Metal & Thermit Corp. d.c. rectifier welder available in 200, 300, 400 amp. ratings. Heavy-duty unit for use in production welding.

104 **Non-Slip Fittings.** Barracuda brass fittings designed by Nelson Foundry Co. to connect plastic pipe. Teeth grip plastic inside and outside of pipe overcoming plastic cold flow property. No reduction in flow. Sizes ½ to 2 in. Several types.

CHEMICALS

125 **Rust Inhibitor.** Banox, a rust inhibitor for use in packing plants, dairies, breweries, cold storage plants and refrigeration brine systems announced by Calgon, Inc. Contains no chromates, alkalies or acids. Odorless, nonpoisonous and nontoxic.

126 **Silicone Water Repellent.** For treatment of leather, Dow Corning Corp. new silicone water repellent. Imparts high water repellency without alteration of appearance. Data sheet gives properties, all pertinent information.

127 128 **Desulphurizing Metal.** (127) Solvay Process Division of Allied Chemical & Dye Corp., brochure on "The Advantages of Desulphurizing Molten Metal with Solvay Dense Soda Ash." In three sections, summarizes advantages, details them, and lists methods of application. (128) Nitrox, a combination cleaner-rust inhibitor. Booklet gives details. For iron and steel tanks.

129 **Safety Solvents.** From Harco Chemical Co. new series of safety solvents for cleaning greasy, oily, dirty machine parts. Replaces toxic carbon tetrachloride. Flash points from 140° F. to 280° F.

130 **Furfuryl Alcohols.** Devoted to furfuryl alcohol and containing information on handling, physical data, chemical reactions, also uses, is a booklet from Quaker Oats Co. Five sections; easy-to-read charts and tables.

131 **Organic Chemicals.** Latest additions to line of Eastman Kodak Co. Forty organic chemicals covered in supplement to complete catalog.

132 **Corrosion-Resistant Cements.** Resistance chart on Pennsylvania Salt Mfg. Co. silicate, resin and sulfur cements. Binder insert for handy reference.

133 **Tergitol Dispersant.** A nonionic surface-active agent, detergent, disperser, and emulsifier described in six-page technical data sheet from Carbide & Carbon Chemicals Co. Physical properties, solubility characteristics, wetting power, stability, etc.

134 **Water Repellent.** Water repellent for most materials from Dow Corning Corp., XS-1. Product is a solution of sodium salts of certain silicones, easily diluted with water and applied by brush, spray, dip or mixing with paper or clay slurries. Data sheet.

135 **Fluorinated Coating.** Fluorinax developed by Nerva-Kote Division, Rubber & Plastics Compound, Inc. Is corrosion resistant, can be brushed, sprayed or dipped. Dries overnight. Can be applied at rate of 250 sq.ft./gal. on metal.

136 **Vinsol.** Up-to-date information on Vinsol, low-cost, dark-colored resin for many applications. Technical booklet from Hercules Powder Co. Discusses applications, use in adhesives, asphalt emulsions, hydraulic cement, ink, paper, protective coating.

137 **Vinyl Coatings.** Chemical and abrasion-resistant vinyl tank linings by Gates Engineering Co. Folder gives components of each type as well as all pertinent data.

138 **Meta Phenols.** Carbide & Carbon Chemicals Co. Newest product of coal hydrogenation, Meta-Phenol 220 now available in tank-car lots. Product is mixture of reactive cresole, xylenols, ethyl phenols with boiling range of 207 to 230° C. Phenolic material about 98% by weight. Data sheet.

139 **Aluminum Paint.** An aluminum paint requiring no prime coat added to line of Joseph Dixon Crucible Co.

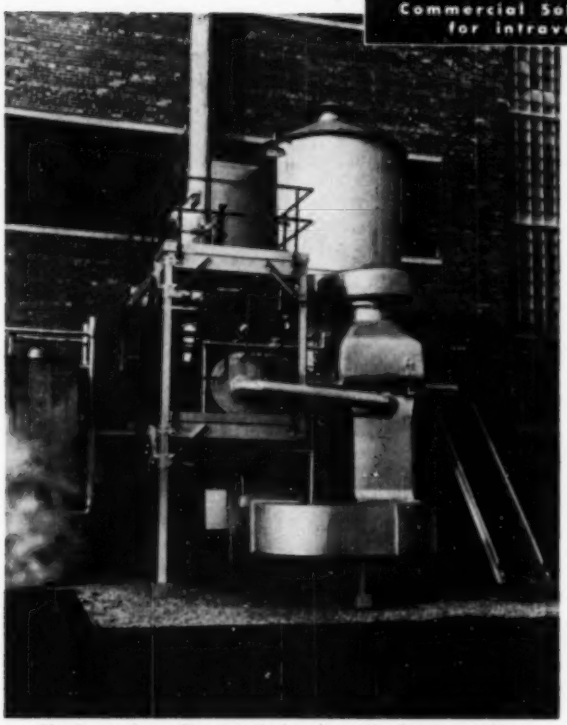
140 **Unplasticized Polyvinyl Chloride.** Made of Exon an unplasticized polyvinyl chloride by Firestone Plastics Co. material designed for unplasticized rigid applications. Can be machined, drilled, sawed, punched, stamped, or cemented easily. Good corrosion resistance. Data sheet gives properties.

141 **Ethylene Oxide Study.** From the Lummus Co. a report on ethylene oxide and ethylene glycol by the new Shell Development Co. process. One section reports on manufacturing and marketing information; the other section on the process, its description, plus costs and utilities summary.

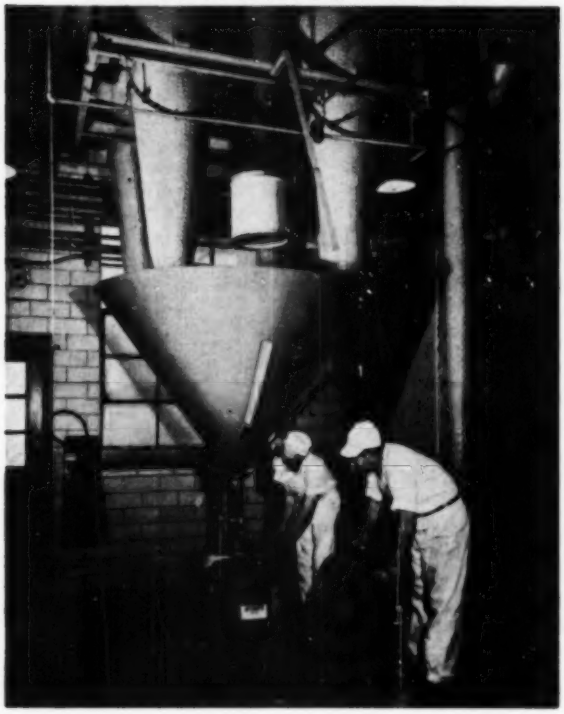
142 **Lubricants.** Bulletin on standard industrial grades and compositions of Molykote lubricants from the Alpha Corp. Highly concentrated, purified molybdenum disulfide, abrasive-free, processed, and refined. Grease consistency mixtures, when to use, thermal conditions, particle sizes, magnetic and electrical properties.

SPRAY DRYER PIONEER

Commercial Solvents meets difficult problem of sterile material for intravenous injection by use of Bowen Spray Dryer



The Bowen Spray Dryer producing the sterile dextran product, is installed out of doors. Ducts run into the building where product collectors and packaging room is located.



Commercial Solvents Produces New Plasma Volume Expander

Originally known as dextran, this product was developed during the war under a Swedish patent. Commercial Solvents, the first to have its product approved in the United States, replaced the original expensive vacuum tray dryer technique with the speedier, lower cost spray drying method. Although dextran was produced exclusively for the armed forces, it is now available under the trade name Expandex to the civilian market.

Recognition is due Commercial Solvents for making available its dextran to our armed forces in Korea and elsewhere and credit should be given to all personnel responsible for its development and production.

Bowen Engineering is proud to have had the opportunity of cooperating in this project.

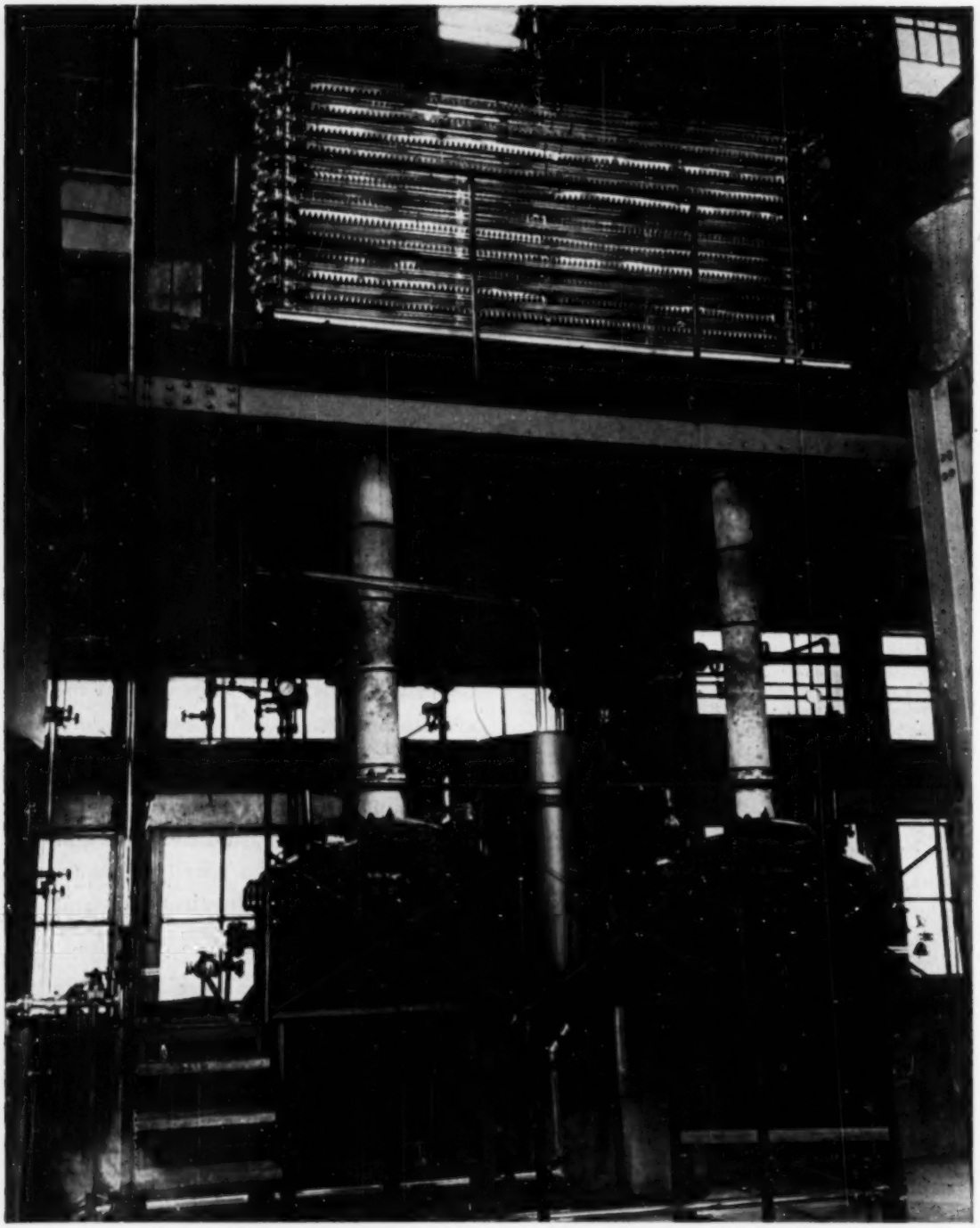
BOWEN ENGINEERING, INC.

NORTH BRANCH 13, NEW JERSEY

BOWEN SPRAY DRYERS
Always Offer You More!

Recognized Leader in Spray Dryer Engineering Since 1926

This manufacturer refuses to gamble



The PYREX *cascade cooler installation at Hydrocarbon Chemicals, Inc. (at top of photo), is used in the finishing operations of many of their highly refined products.*

The cooler consists of 2 banks of 11 two-inch glass tubes. The glass provides the corrosion resistance necessary to protect against product contamination and excessive replacement costs.

200 ft. of PYREX *pipe transfer solutions from catalyst room to glass-lined reactors, from reactors to cooler, and from cooler to glass-lined storage tanks. No breakage problem has been encountered although solutions at 210° F. are sometimes run through the pipe at 32° F. and lower. Product purity is a primary consideration.*

with product purity

That's why he specified

PYREX "Double-Tough" Glass Pipe
brand

Knowing the character of the chemicals its equipment must handle, Hydrocarbon Chemicals, Inc., Newark, N. J., chose the most practical piping material which would insure its products against contamination and at the same time eliminate all chances of corrosion and subsequent high replacement costs.

That material was PYREX® brand Double-Tough Glass Pipe which resists virtually all acids (except hydrofluoric) and stands up well under most caustics.

The savings in replacement costs and unspoiled product batches have paid for the installation several times over, reports Mr. Frank T. Andrews, President.

No breakage problems

Mr. Andrews also reports "no breakage problems" with PYREX pipe, even though his men sometimes run concentrated acids at 210° F. into pipe that's under 32° F. "There would have to be a lot of breakage before I would abandon the use of glass pipe," Mr. Andrews adds.

The low coefficient of expansion of PYREX brand glass No. 7740 accounts for this ruggedness. It permits heavier wall construction than would be possible with ordinary glass. This greatly increases its resistance to physical impact.

Glass pipe offers these basic advantages

Mr. Andrews cites the following basic advantages his company has realized from using PYREX pipe:

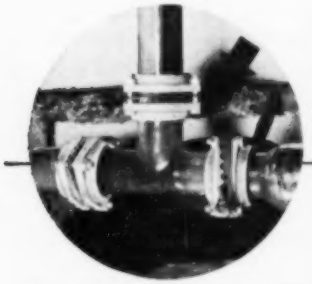
1. It withstands the most corrosive acids. Thus pipeline replacement and maintenance costs are minimized. Production time is saved.

2. Its chemical stability also protects product purity. This is particularly important since many of his products go to pharmaceutical manufacturers.

3. It is easy to clean. Hydrocarbon Chemicals simply run a detergent through the lines and flush with hot water.

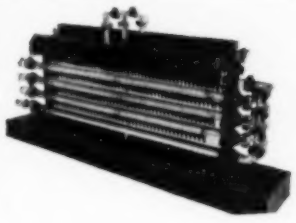
4. You can make visual checks through its transparent walls for cleanliness and flow conditions.

These may be basic reasons why glass pipe will pay for itself many times over in *your* plant. If you are faced with a persistent corrosion or product contamination problem, we invite you to investigate PYREX brand glass pipe and cascade coolers. The coupon makes it easy for you to get started.



Unretouched photo shows graphic example of corrosion resistance of glass pipe in chemical drain line. The glass will never corrode like the metal pipe (arrow).

PYREX cascade coolers are now available from Corning in convenient packages. Your own men can assemble them in a few hours. They can be mounted on floor, wall, or ceiling.



CORNING GLASS WORKS
CORNING, NEW YORK
Corning means research in Glass

The following conveniently located distributors stock and sell PYREX pipe and fittings. Contact the one nearest you for full information.

BELMONT, CALIFORNIA
Glass Engineering Laboratories

FRESNO 17, CALIFORNIA
Valley Foundry & Machine Works

NEW HAVEN, CONNECTICUT
Macalaster Bicknell Company

ATLANTA, GEORGIA
Southern Scientific Company

CHICAGO 44, ILLINOIS
Fred S. Hickey, Inc.

NEW ORLEANS, LOUISIANA
W. H. Curtin & Company

CAMBRIDGE 39, MASS.
Macalaster Bicknell Company

ST. LOUIS 4, MISSOURI
Stemmerich Supply Inc.

LODI, NEW JERSEY
Mooney Brothers Corporation

ALBANY 5, NEW YORK
A. J. Eckert Industrial Sales Corporation

BUFFALO 13, NEW YORK
Buffalo Apparatus Co.

ROCHESTER 3, NEW YORK
Will Corporation

HATBORO, PA.
Sentinel Glass Company

PITTSBURGH 19, PA.
Fisher Scientific Company

HOUSTON 7, TEXAS
W. H. Curtin & Company

SEATTLE 4, WASHINGTON
Scientific Supplies

TORONTO, ONTARIO, CAN.
Fisher Scientific Company, Ltd.

MONTREAL 3, QUEBEC, CAN.
Fisher Scientific Company, Ltd.

VANCOUVER, B. C., CAN.
Scientific Supplies

CORNING GLASS WORKS
Dept. EP-9, Corning, N. Y.

Please send me the printed information checked below:

☐ "PYREX brand Glass Pipe in the Process Industries" (EA-1)

☐ "PYREX brand 'Double-Tough' Glass Pipe and Fittings" (EA-3)

☐ "PYREX Cascade Coolers" (PE-8)

Name.....

Title.....

Company.....

City.....Zone.....

State.....

Table 2.—Opinions on Requirements for Active Membership

Question No. 2. Do you feel that the requirements for Active membership are properly designed and maintained, etc.?	Replies from Active Members		Replies from Assoc. Members		Replies from Junior Members		Total * Replies	
	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent
Yes	2227	75.8	308	67.3	2454	57.1	4989	65.0
No	479	16.3	82	17.9	617	14.4	1178	15.2
Undecided	211	7.2	50	10.9	682	15.8	943	12.2
Don't know requirements	20	0.7	18	3.9	546	12.7	584	7.6
Total replies	2937	100.0	458	100.0	4299	100.0	7694	100.0

* The differences between the total figures presented above and the totals given in the summary article in the April, "C.E.P.," page 17, are due to the number of rejects by the I.B.M. machine arising from improper replies to the question when broken down by membership. This discrepancy will be noted throughout all these comparisons.

Table 3.—Opinions on Nominating and Electing Officers and Directors

Question No. 3. Are you satisfied with the present procedure for nominating Officers and Directors?	Replies from Active Members		Replies from Assoc. Members		Replies from Junior Members		Total Replies Received		
	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent (A)	Per cent (B)
Yes	2378	81.2	292	64.7	2127	49.6	4797	62.5	...
No	202	6.9	25	5.5	269	6.3	496	6.5	...
Undecided	171	5.8	40	8.9	349	8.1	560	7.3	...
Don't know procedure	179	6.1	94	20.8	1546	36.0	1819	23.7	...
Total replies	2930	100.0(A)	451	100.0	4291	100.0	7672	100.0	...
	(2930)	(38.2)(B)	(451)	(5.9)	(4291)	55.9	(7672)	.....	(100)
Question No. 4. Are you satisfied with the present procedure for electing Officers and Directors?									
Yes	2571	87.7	307	76.5	2319	54.1	5197	68.2	...
No	138	4.7	30	7.5	386	9.0	554	7.3	...
Undecided	119	4.1	35	8.7	322	7.5	476	6.3	...
Don't know procedure	102	3.5	29	7.3	1256	29.3	1387	18.2	...
Total replies	2930	100.0(A)	401	100.0	4283	100.0	7614	100.0	...
	(2930)	(38.4)(B)	(401)	(5.3)	(4283)	(56.3)	(7614)	.....	(100)

of membership considerations are involved. This is a point that might have a bearing on the need for or the value of different grades of membership.

Active Membership

Question 2 asked, "Do you feel that the requirements for Active membership are properly designed and maintained so that the attainment of this grade of membership is recognized as a real professional achievement in chemical engineering?" The over-all replies were 4,995 (64.8%) in the *yes* column, 1,191 (15.5%) *no's*, 943 (12.2%) who were undecided, and 581 (7.5%) who didn't know the requirements. While 5,000 members felt that the requirements for Active membership were properly designed and maintained, it was felt desirable to obtain further information on those who did not feel the same way. An analysis of these replies by grade of membership is presented in Table 2. It will be noted here that 2,227 Active members (75.8%) were satisfied that the Active membership grade was properly designed and maintained; 308 Associate members (67.3%) and 2,454 or 57.1% of the Junior members had similar sentiments. On the other hand 28.6% of the Juniors could not make up their minds or else didn't know.

Opinions on Nominating and Election Procedures

Questions 3 and 4 asked whether the members were satisfied with nominating and electing procedures for officers and directors of the Institute. The summary replies (April "C.E.P.") indicated that 64% were satisfied with nominating procedures and 67.7% were satisfied with the methods for electing. A further analysis of these two questions was made by grade of membership, with the results presented in Table 3. A somewhat different picture appears. As one might assume from the specifications in the procedures, 81.2% of the Active members were satisfied with the status quo on nominating and 87.7% on electing. The Associate members followed with 292 or 64.7% in the *yes* column for nominating and 307 or 76.5% for election procedures. However, less than half of the Junior members (2,127 or 49.6%) were satisfied with nominating procedures, but 54.1% were satisfied with election methods. A study of the write-ins indicates that there is a considerable degree of dissatisfaction in this area. At a future date further analysis by geographical sections will be made of this point. A disturbing fact is revealed in Table 3, i.e., 23.7% of those replying did not know the methods for nominating; 36% or 1,546 Junior members did not know. Similarly a total of 18.2% did not know the election procedures, including 1,256 or 29.3% of the Junior members. On a complete membership basis—even assuming no similar tendency on the part of those who did not return the Questionnaire—the figures just given mean that at least 11.5% do not know the election procedures.

Chemical Engineering Progress

Many of the comments written into the questionnaire had to do with "C.E.P." Moreover, Question 6 asked directly, "How well do you like 'C.E.P.'?" The responses to this question were:

		%
a. Very well	1,360	17.6
b. Well enough	4,228	55.0
c. Not very well	1,868	24.2
d. Not at all	137	1.7
e. Undecided	118	1.5
Total	7,711	100.0

In order to find out more about those who were expressing these preferences, the answers given to Question 6 were correlated against the replies to Question 17 (Academic degree held), Question 26 (Field of work), and Question 27 (Relationship to their main business). These data are shown in Table 4, parts A, B, C.

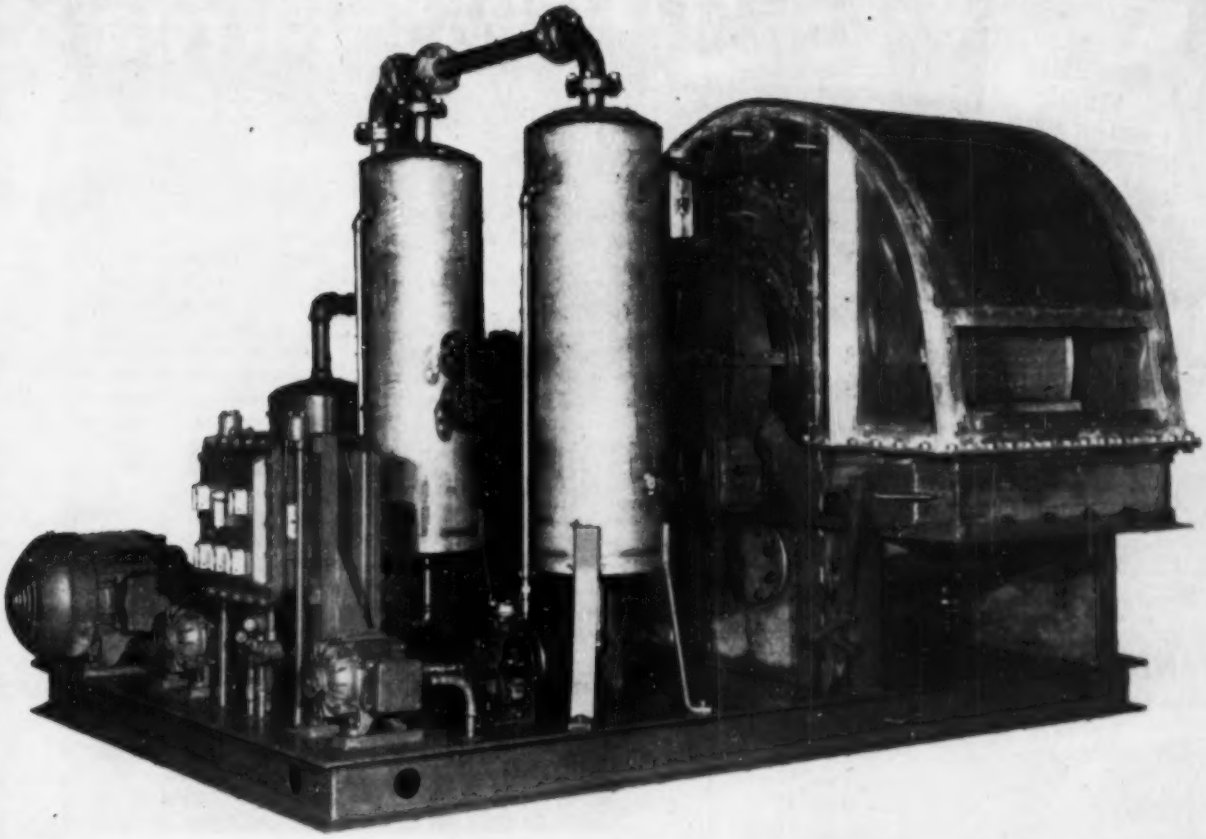
In Part A, there appears no significant differences in the answers to the question (6) depending upon the kind of college degree obtained. Parts B and C afford a means of breaking these totals down into important and meaningful components.

The smaller numbers in Table 4 have been eliminated from consideration since they are not statistically important. From Part B a table of preferences is prepared for the various groups listed.

(*Table 4 on page 54*)

(Remainder of article will appear in Oct.)

Eimco Pilot Filter Stations Give Accurate Data



The machine pictured above is another example of Eimco custom filter design and construction. The filter is installed in one of the country's large pharmaceutical plants producing antibiotics and the construction incorporates Eimco's popular package unit design.

The filter unit is a 4 foot diameter by 2 foot face size — of all type 316 stainless steel materials with multiple cake washing apparatus, vapor tight hood, roller discharge and other features. The filter with all of its accessories is mounted on a single platform with all piping and valves connected, all electrical wiring from motors to a central control panel. The unit arrives at the user's plant ready to run.

When your problem involves filtration consult an Eimco engineer first. Our more than half a century of service to the process industries gives us the necessary background to specify and build the proper equipment to do the best job for you at least expense.

Eimco manufactures all types of filtration equipment — our purpose is to suit the best type to your needs whether it be pressure, vacuum, gravity or any combination of these types.

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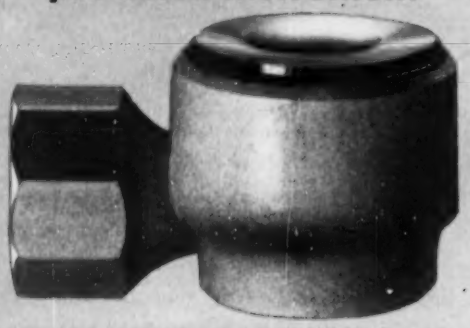

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CANDIDATES FOR MEMBERSHIP IN A. I. Ch. E.

The following is a list of candidates for the designated grades of membership in A.I.Ch.E. recommended for election by the Committee on Admissions.

These names are listed in accordance with Article III, Section 7, of the Constitution of A.I.Ch.E.

Objections to the election of any of these candidates from Active Members will receive careful consideration if received before October 15, 1953, at the Office of the Secretary, A.I.Ch.E., 120 East 41st, New York 17.

Applicants for Junior Membership

Aaron, H. Osborne, *Wilmington, Del.*
Aikens, Alexander E., *Jr., Philadelphia, Pa.*
Armani, Roland Joseph, *Cicero, Ill.*
Aschoff, Alroy F., *St. Louis, Mo.*
Bankston, P. Talmage, *Atlanta, Ga.*
Battershall, David D., *Houston, Tex.*
Bindseil, Edwin R., *Erie, Pa.*
Bridges, Wilson B., *Groves, Tex.*
Buchanan, Jack S., *Nekoosa, Wis.*
Burkhardt, Donald B., *Reading, Mass.*
Coggins, Patrick E. Jr., *Wilmington, Del.*
Cohen, Morton, *New York, N. Y.*
Corbett, Bernard L., *Pittsburgh, Pa.*
Curley, Arthur T. Jr., *Liberty Corner, N. J.*
Day, Robert W., *Lakeland, Fla.*
Dobson, Ernest W., *Marcus Hook, Pa.*
Donahue, Joseph M., *Winchester, Va.*
Dorweiler, Vernon, *Des Moines, Ia.*
Dougherty, Robert W., *Charleston, W. Va.*
Fields, Martin, *Cincinnati, Ohio*
Freifeld, Milton, *Springfield, Mass.*
Fremed, Raymond F., *Brooklyn, N. Y.*
Fuerst, Peter E., *Ringoes, N. J.*
Gann, Paul W., *Decatur, Ala.*
Geyh, Charles Anthony, *Niagara Falls, N. Y.*
Gillespie, G. Richard, *Gibbstown, N. J.*
Goldstein, Herbert M., *New York, N. Y.*
Gottemoller, John V., *Niagara Falls, N. Y.*
Grace, Lloyd F., *Pittsburgh, Pa.*
Graff, John H., *Charleston, W. Va.*
Greco, Saverio G., *Brooklyn, N. Y.*
Grellinger, George N., *Bay Village, Ohio*
Heady, Orville E., *Denver, Colo.*
Hedley, Wm. Henby, *Clayton, Mo.*
Hegarty, William, *Gloversville, N. Y.*
Hickman, Robert W., *Waynesboro, Va.*
Hill, James H., *Richmond, Va.*
Howard, C. Lewis, *Burrton, Kan.*
Hurd, Clifford T., *Baltimore, Md.*
Hutchinson, Donald O., *Baton Rouge, La.*
Jordan, J. Irwin, *Jr., Duncan, Okla.*
Kietzman, R. C., *Santa Monica, Calif.*
Kilpatrick, Lester L., *Huntsville, Ala.*
Kirschner, Joseph, *New Orleans, La.*
Klobe, Jerry S., *Oak Ridge, Tenn.*
Kopfhammer, Gene, *West Allis, Wis.*
Lake, James H., *Kalamazoo, Mich.*
Lederman, Peter B., *Wood River, Ill.*
Liggett, John F., *Akron, Ohio*
Lindstrom, Richard S., *Melrose, Mass.*
Lovelace, William W., *Jr., Carlsbad, N. M.*
Lynch, Edward J., *Berkeley, Calif.*
MacDougall, Donald A., *Dayton, Ohio*
Margiloff, Irwin B., *Joliet, Ill.*
McGibney, Ralph E., *Pittsfield, Me.*
McTaggart, Robert B., *Springfield, Mass.*
Mikesell, William A., *Jr., Cactus, Tex.*
Miller, John L., *Niagara Falls, N. Y.*
Nemecek, John M., *New York, N. Y.*
Nicholas, Aristides S., *Grand Rapids, Mich.*
Okrent, Eugene Henry, *Brooklyn, N. Y.*
Onubogu, Harold N., *Ann Arbor, Mich.*
Parker, Dewey P., *St. Louis, Mo.*
Pecorini, Hector A., *Long Island City, N. Y.*
Place, Harold G., *College Station, Tex.*
Powell, Arthur R., *Ozone Park, N. Y.*

(*Continued on page* 48)

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6. Dryer length and design
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9. Possible simple changes in stock preparation prior to drying, to attain maximum quality and efficiency.
10. Controls required to maintain quality and quantity drying in uniform, continuous production.

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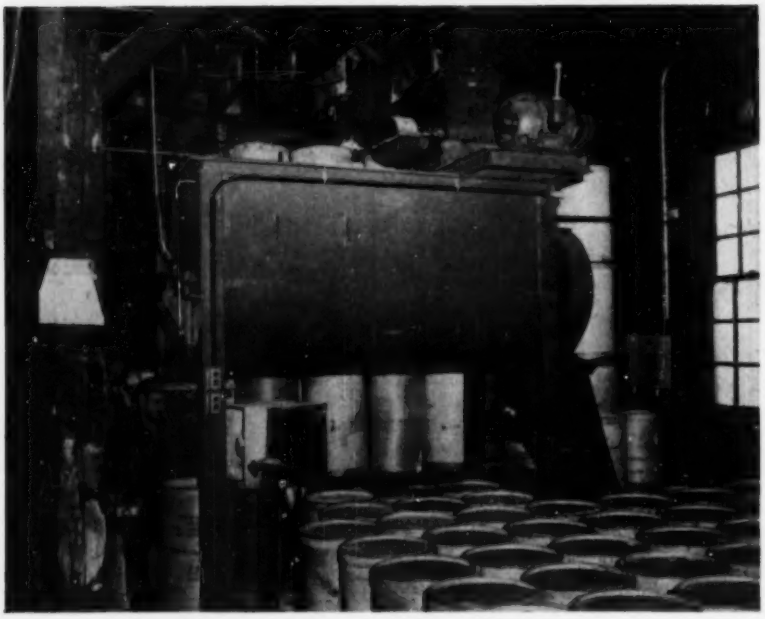
Two Paul O. Abbé Mixers Serve ECCO Chemical Corp.



Pictured here is the 2000 pound capacity Paul O. Abbé Mixer at the Ecco plant. The 1000 pound mixer is on the floor above.

For fast, efficient mixing of salts for heat treating, Ecco Chemical Corporation has two Paul O. Abbé heavy duty Mixers, one of 2000 pounds capacity, the other of 1000 pounds.

More than fifty different ingredients are mixed in these machines, including cyanide and chloride salts.

- Every part is designed to take shocks and wear for many years without breakdowns.
- All moving parts, such as gears and drives, are guarded to conform with rigid safety requirements.
- Blades and shafts are oversize.
- Sealed antifriction bearings are mounted away from ends of the mixing bowl.
- Special packing boxes seal the ends against leakage.
- Mixing bowls are lined with a special alloy steel that reduces wear.

If you have a mixing problem of any kind, send for our catalog V. For individual advice write to

PAUL O. ABBÉ

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SECRETARY'S REPORT

S. L. TYLER

No formal meeting of the Executive Committee was held during the month of August. The only necessary business was the election of applicants for membership; the Executive Committee approved the election of all those whose names appeared in the July issue of C. E. P. to the grades of membership for which they applied.

LUDWIG PRANDTL DIES IN GERMANY

Ludwig Prandtl, internationally known physicist, died on Aug. 19 in Goettingen, Germany, at the age of 78. Known to chemical engineers mainly through the dimensionless group that bears his name, Professor Prandtl was concerned primarily with aerodynamics. He directed the Institute for Technical Physics of the University of Goettingen and the Kaiser Wilhelm Institute for Fluid Motion Research. Prandtl's early experience was in engineering after he received a Ph.D. from the University of Munich.

NATIONAL LEAD TO DISTRIBUTE NICKEL

National Lead Co. has announced that it has assumed responsibility for distribution of all production of the Government-owned nickel plant at Nicaro, Cuba. In this connection the firm has formed a Nickel Sales Division at 111 Broadway, New York 6.

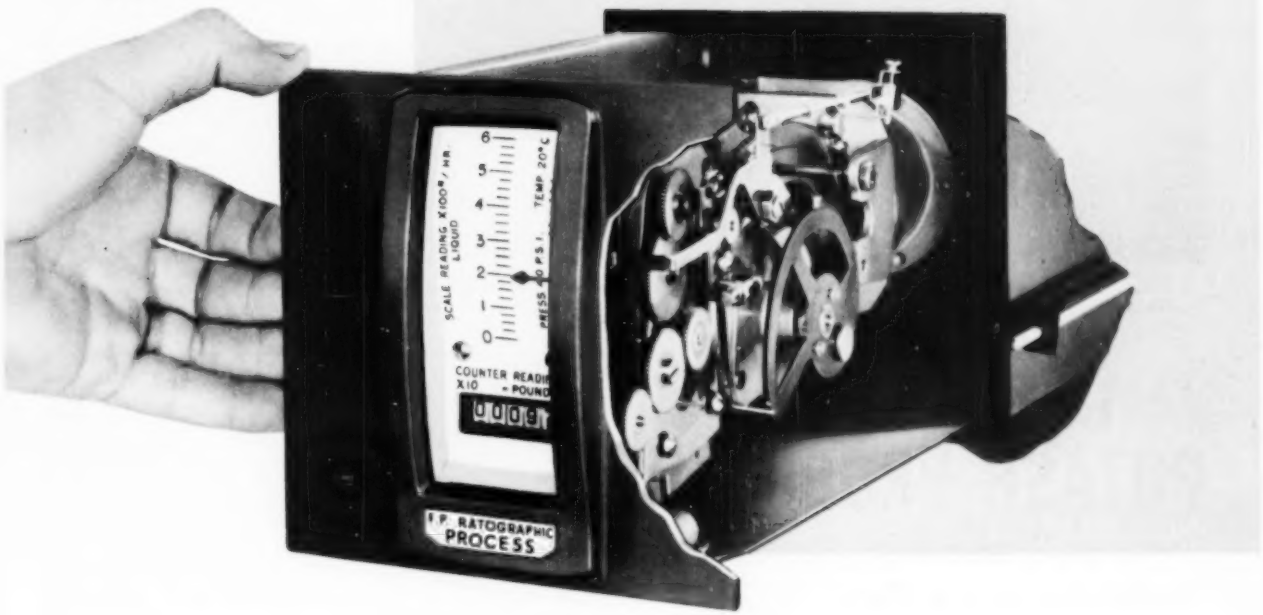
CANDIDATES

(*Continued from page 46*)

Rothacker, Donald L., *New York, N. Y.*
Ruscilli, Albert E., *Alton, Ill.*
Schlesing, Darwin B., *Jacksonville, Ill.*
Sheldon, E. Edward, *Charlotte, N. C.*
Sornson, John D., *New York, N. Y.*
Spears, Robert C., *Avon Lake, Ohio*
Stanton, Roland J., *Bellingham, Wash.*
Stickeler, George Peter, *Bronx, N. Y.*
Tarr, Fred P. *Springfield, Mass.*
Taylor, Jamess Reuel, *Dearborn, Mich.*
Tewksbury, James, *Berkeley, Calif.*
Thomas, Donald C., *St. Albans, W. Va.*
Turbett, Robert J., *Montclair, N. J.*
Vannucci, Quintino, *Bridgeport, Conn.*
Vietinghoff, William F., *Reseda, Calif.*
Vlcek, Norman F., *Borger, Tex.*
Walden, G. H. Edward, *Ridley Park, Pa.*
Walker, Harry S., *Darby, Pa.*
Walter, Edwin P., *El Dorado, Kan.*
Warrell, Lincoln A., *Carlisle, Pa.*
Webb, Joseph C., Jr., *Lake Jackson, Tex.*
Whitmeyer, Herbert F., *Union, N. J.*
Winton, Glen Peter, *Evanston, Ill.*
Withey, James V., *Darby, Pa.*
Zeitvogel, Frederick J., *Mount Vernon, N. Y.*

NEW

Ratographic* totalizer



complete with continuous rate indication

- continual integration at rate of 24 times per minute
- dust-proof drive mechanism immersed in oil
- heavy duty 100 rpm – 72 pole synchronous motor
- standard size pneumatic receiver and integrator
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- accuracy within 1% of full scale

Here, for the first time, is a *full-size*, rugged totalizer – so designed that it can be used in full size, miniature or graphic panels. A companion to the F & P Ratographic miniature indicator, it is another step in complete process instrumentation developed and perfected by the skilled engineers at Fischer & Porter Company.

The entire unit occupies only six inches square of panel space. In extended position, as shown, instrument continues to function, thus easily enables observation of mechanism. The highly accurate integrating unit gives the equivalent of continuous integration. The many other new features combined in this instrument suggest a careful comparison. Full information on request.

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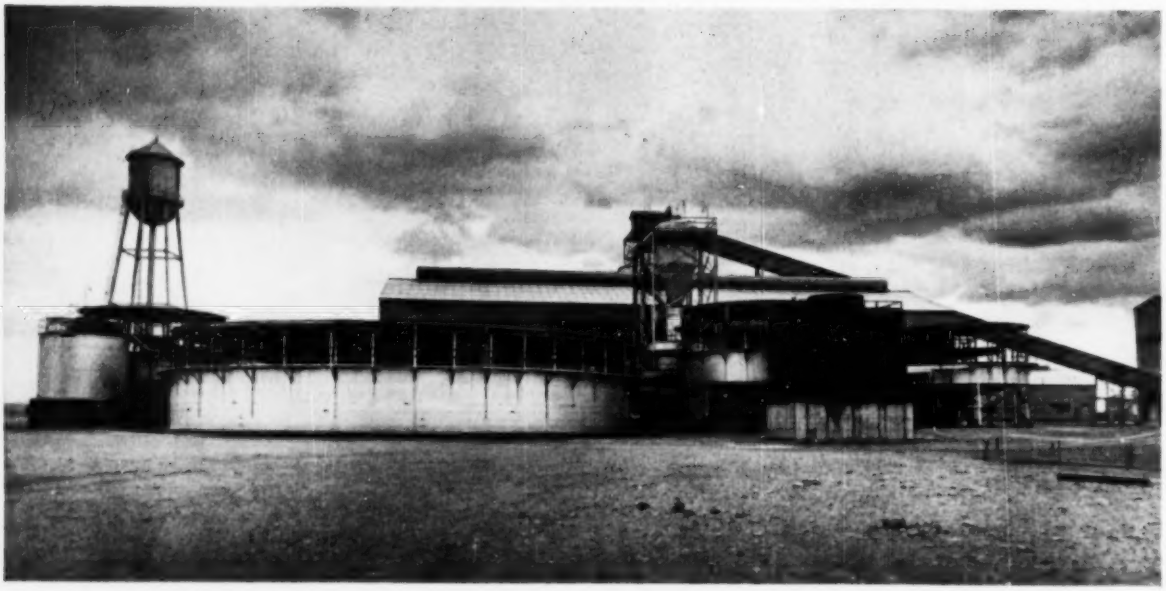
Company owned sales and service branches strategically located throughout the world.



Overall view of the plant with a 120′ dia. Dorr Thickener in the left foreground handling flotation tailings. A 40′ dia. Dorr effluent Thickener and 40′ dia. Dorr Hydroseparator are at the right. All three units are covered to prevent temperature increases resulting from the sun's rays.

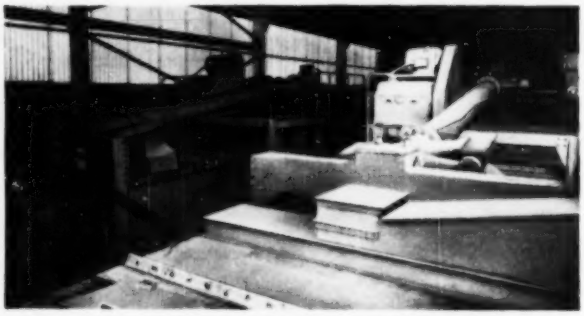
NEW MEXICO POTASH PRODUCER

Combines Chemical and Metallurgical Techniques at New Plant . . .

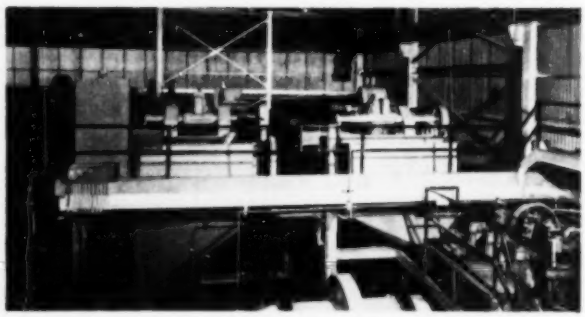
A new U. S. producer for the quality potash market, Duval Sulphur & Potash Company recently started up this modern plant near Carlsbad, New Mexico. A perfect example of the growing convergence of chemical and metallurgical techniques, the plant makes skillful use of the latest developments in both fields.

The flowsheet includes crushing, grinding, classification, hydroseparation, flotation, thickening, centrifuging, crystallization and drying.

At Duval, as throughout the chemical and metallurgical industries, Dorr equipment and techniques play a vital part in wet processing flowsheets. For more information on the scope of the Dorr technical service, write for bulletin No. 7002. The Dorr Company, Stamford, Conn. *In Canada:* 26 St. Clair Avenue, E., Toronto 5.



Closeup of two Duplex Dorr HX Classifiers. The Primary at right handles raw crushed salt which has been pulped with return brine. Sands go to a rod mill and fines to the Hydroseparator.



General view of the milling section. Rod mill discharge goes to the Secondary Classifier at the right. Sands are discharged to conditioners and fines overflow to the Hydroseparator.

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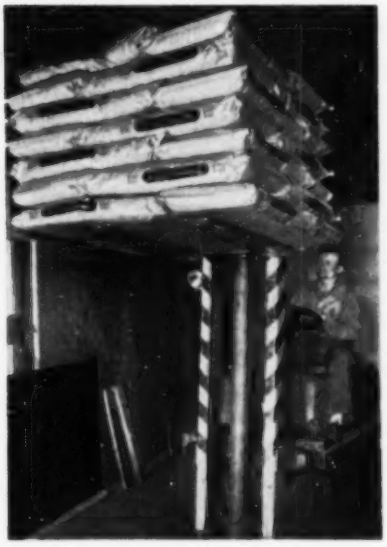
(Continued from page 48)

NEW SHIPPING METHOD



A method for shipping bagged phthalic anhydride in units that can be unloaded with conventional handling equipment at a saving of approximately 11 manhours a carload was introduced recently by Monsanto Chemical Co. Basis of the method is a 25-bag unit built up on an expendable fiberboard sheet. The layers in each unit, interlocked pinwheel fashion, are glued bag to bag. The company claims that a car loaded in this way can be unloaded by two men with a fork lift truck in about 2 hours; whereas hand unloading requires approximately 5 hours and three men.

AEROSOL CAMERA AT STANFORD RESEARCH

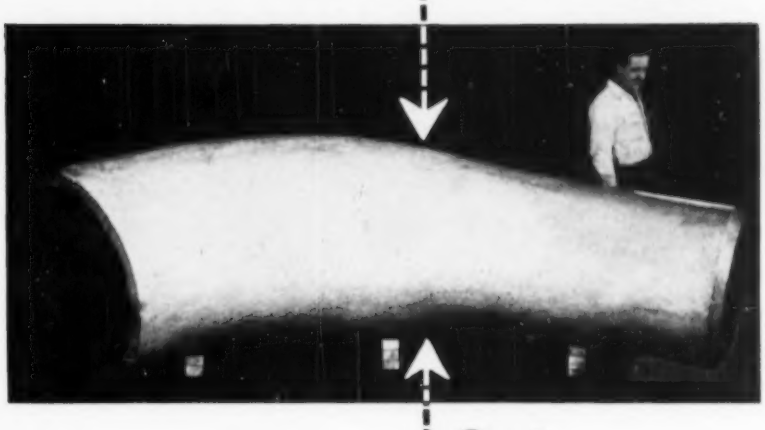
A new camera for photographing microscopic particles floating free in the atmosphere has been announced by Stanford Research Institute. Currently being tested, the experimental camera can, according to the institute, photograph aerosols as small as 0.002 in.

Paul Magill, technical director of the research laboratories, says, "The aerosol camera will give air researchers an opportunity to study aerosols in their natural state. Previous microscopic techniques have required collection of the particles on slides." When fully perfected, the 500-lb. camera, Magill continued, should indicate whether or not the process of settling or precipitating particles upon a slide alters or destroys them.

The depth of field of the camera is 200μ. Instead of a mechanical shutter, pulsed flashes of a narrow-beam light provide the film exposure. The flashes, of 2,000,000 cp. intensity, may be of 1, 4, or 10 μsec. duration and may be regulated at any number up to 100 exposures a second. The 5- by 7-in. film may be exposed as often as desired.

DURALOY

This Casting



Casting weight
21,000 pounds

Shipping weight
14,000 pounds

Alloying Elements
38% Ni., 18% Cr., 2% Mo.

Set a Record!

It's the weight rather than the Ni-Cr content that's the record.

We've cast many a piece with such a high Ni-Cr combination. But this represents the largest casting we have ever made. And it took careful scheduling of our entire battery of electric furnaces, with a double melt from two smaller furnaces.

Next followed a thorough X-ray for hidden flaws with our 400,000 volt unit. Then rough-finishing to specifications.

The significant fact is that this casting, the first of this size we have ever produced and destined for a most important high priority processing job, passed inspection with flying colors. *There was no reject here.* It is indicative of the skill of our metallurgists and foundrymen in turning out high alloy castings.

If you are looking for this kind of service, make Duraloy your casting source.

THE DURALOY COMPANY

Office and Plant: Scottdale, Pa. • *Eastern Office:* 12 East 41st Street, New York 17, N.Y.

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"Made-to-Order" for CORROSIVE SERVICE

Towers, absorbers, scrubbers

Pipe, duct and fittings

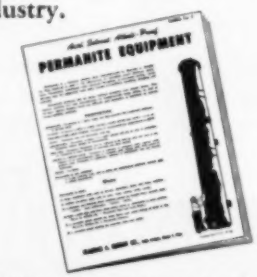
Jars, tanks, sumps, trays

Separators, mixing kettles, surge tanks

The large diameter ductwork above is "made-to-order" for handling corrosive fumes because it is made of Permanite.

Permanite is a furfural alcohol resin structural material reinforced with chemical Fibreglass, which can be formed to almost any shape. It is light weight but very strong and tough and presents a hard non-absorbent surface. Permanite Equipment is corrosion proof throughout its entire body. It will handle most acids including HF, HCl, as well as oil, alkalies and organic solvents to 280°F.

Permanite is used in the construction of many types of chemical handling equipment, large and small. Although individually engineered, Permanite equipment is relatively low in cost and economical in operation. Because of its light weight, it offers an added advantage of speed and facility in handling, shipping and erecting. It is being used for handling corrosives in just about every chemical process industry.



Send for illustrated Bulletin No. 6-F Permanite Equipment, or Bulletin No. 1, Permanite Pipe and Ductwork, and learn how Permanite can help solve your corrosion problems.

Maurice A. Knight 709 Kelly Ave., Akron 6, Ohio

Acid and Alkali-proof Chemical Equipment

CHEMICALS SHOW IN PHILADELPHIA

The twenty-fourth Exposition of Chemical Industries will be held this year at Commercial Museum and Convention Hall in Philadelphia instead of in New York, the traditional location of this biannual exhibition. The week of Nov. 30 to Dec. 5 is the date for the exhibition, which, according to its sponsors, will be the largest of its kind ever held.

SHELL CHEMICAL ADDS TO GLYCERINE OUTPUT

Construction of a new plant to produce allyl chloride and epichlorohydrin was announced last month by Shell Chemical Corp. To be located at Norco, La., the plant will increase Shell Chemical's glycerine production by 25,000,000 lb. annually and also produce additional quantities of epichlorohydrin and Epon resins.

The new plant is designed to operate in conjunction with the Shell Oil Co. refinery at Norco and will use propylene and other feed stocks produced by the refinery. Completion of the chemical plant is expected by late 1954.

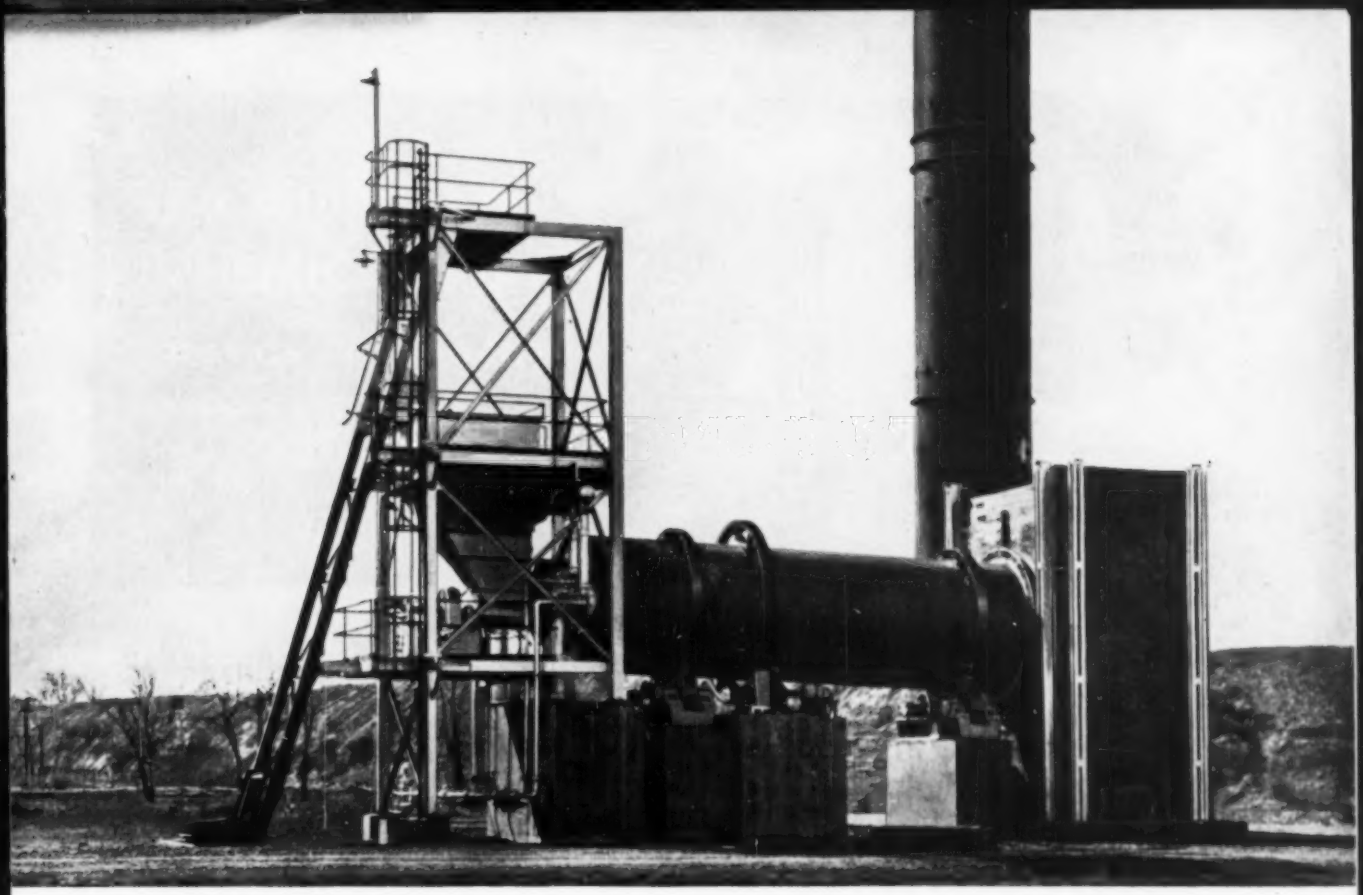
NEW FILTER COMPANY FORMED IN BUFFALO

A new subsidiary company, Process Filters, Inc., has been formed at Buffalo, N. Y., by Bowser, Inc., a Chicago equipment firm. The new company will design and engineer industrial liquid-control equipment, especially filters. Edward A. Ulrich is vice-president and general manager of the Buffalo company. He was formerly with Niagara Filter, which was acquired by American Machine and Metals Co., Inc., earlier this year.

ANTHRAQUINONE PROCESS STUDIED AT CALCO

A process for the manufacture of anthraquinone from naphthoquinone and butadiene is under pilot-plant development at the Calco Chemical Division of the American Cyanamid Co., Bound Brook, N. J.

Anthraquinone, a key intermediate in the synthesis of vat dyes, has been made in this country primarily by the phthalic anhydride-benzene route. European manufacturers have generally preferred the older process of oxidation of anthracene. Heretofore the procedure under study at Calco, which Diels and Alder were first to describe, had been considered economically unfeasible because of the high cost of naphthoquinone production.

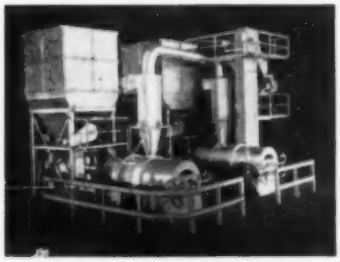


rotary kiln Burns Waste

. . . provides easy, economical, smoke-free disposal of still and tank bottom sludge, office waste, rags, food waste, and other oil refinery, industrial or commercial wastes.

● Material to be burned is raised in the skip bucket and fed into the brick lined kiln with a specially designed feeder. Kiln can be rotated at various speeds, permitting the burning time to be altered to meet changing requirements. Ashes are collected in the brick chamber. An auxiliary oil burner is provided for use when the materials are not readily combustible. Consult Bartlett-Snow on your next drying, cooling, calcining, waste disposal or other heat engineering problem. Our wide experience can save you both time and money!

Special Stainless Steel Batch Dryer for Drying Fine Catalyst without Dust Loss.



Two Complete Drying Systems, Can Be Operated Together—or Singly—to Meet Varying Plant Requirements.

DESIGNERS ENGINEERS

BARTLETT-SNOW
CLEVELAND 5, OHIO

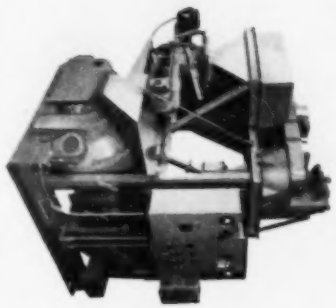
FABRICATORS ERECTORS

Dryers • Coolers • Calciners • Kilns

"Builders of Equipment for People You Know"

DRY GRINDING UNIT

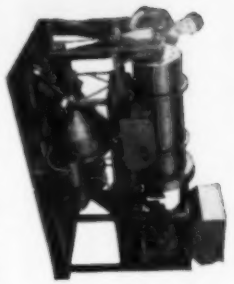
Make power connections only and the Hardinge Dry Grinding Unit is ready to perform. Self-contained and portable, 78" high. Complete with Constant-Weight Feeder, Conical Mill, Loop Classifier, dust collector, product collector and "Electric Ear" grinding control.



"Packaged Pulverizers"

WET GRINDING UNIT

Make power and water connections only and the Hardinge wet grinding unit is ready to perform. Self-contained and portable, 67" high. Includes Conical Mill, Counter-Current Classifier, launders, feeder, pump and "Electric Ear" grinding control.



HARDINGE COMPANY, INCORPORATED

YORK, PENNSYLVANIA

Table 4.—Regarding Chemical Engineering Progress

	Question 6. Broadly considered, how well do you like Chemical Engineering Progress?												
	Very well		Well enough		Not very well		Not at all		Undecided		Total		
	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent	
A							X	X	X	X			
Question 17—Regarding education, please check highest degree obtained.													
a. No degrees	28	40.0	31	44.3	8	11.4	0	0	3	4.3	70	100	X
b. Undergraduate	665	16.2	2184	53.1	1115	27.1	80	1.9	68	1.7	4112	100	
c. Masters, professional, etc.	446	19.5	1313	57.3	470	20.5	31	1.4	29	1.3	2289	100	
d. Doctorate	215	17.6	698	57.3	267	21.9	26	2.1	14	1.1	1220	100	
Total or Average	1354	17.6	4226	54.9	1860	24.2	137	1.8	114	1.5	7691	100	
B													
Question 26—What is your occupation?													
a. Research and development	425	16.9	1443	57.4	571	22.8	38	1.5	34	1.4	2511	100	
b. Design (Process, plant, mechanical, engineering, drafting, etc.)	243	21.2	671	58.6	208	18.2	13	1.1	10	0.9	1145	100	
c. Plant operation, construction, tech. services, maintenance, equipment, production	278	15.4	927	51.5	534	29.6	37	2.1	25	1.4	1801	100	
d. Teaching, education	71	19.4	205	56.0	78	21.3	8	2.2	4	1.1	366	100	
e. Consulting	55	28.5	80	41.5	48	24.8	6	3.1	4	2.1	193	100	
f. Economics, market analysis, purchasing, financial, etc.	15	9.3	88	54.3	53	32.7	6	3.7	0	0.0	162	100	
g. Sales (Development, technical advertising)	59	15.2	203	52.3	109	28.1	9	2.3	8	2.1	388	100	
h. Placement, training or employee, labor or public relations	3	9.7	20	64.5	5	16.1	1	3.2	2	6.4	31	100	X
i. Management	9	1.3	463	66.1	191	27.3	16	2.3	21	3.0	700	100	
j. Special services (Patents, library)	14	21.2	28	42.5	19	28.8	2	3.0	3	4.5	66	100	X
k. Other unlisted fields	19	11.7	98	60.5	40	24.7	2	1.2	3	1.9	162	100	
Total or Average	1191	15.8	4226	56.2	1856	24.7	138	1.8	114	1.5	7525		
C													
Question 27—What is your relationship to your main business?													
a. Self-employed	50	27.6	77	42.5	47	26.0	5	2.8	2	1.1	181	100	
b. Employee of private firm or corporation	1140	17.1	3692	55.4	1617	24.4	116	1.7	96	1.4	6661	100	
Employee of Federal Government, etc.	53	18.8	139	49.3	77	27.3	6	2.1	7	2.5	282	100	
Employee of educational institution	81	20.2	220	54.8	89	22.1	9	2.2	3	0.7	402	100	
c. Member of Armed Forces	12	18.5	38	58.4	11	16.9	0	0.0	4	6.2	65	100	X
d. Student	10	18.5	30	55.6	13	24.1	0	0.0	1	1.8	54	100	X
e. Retired	5	17.2	12	41.4	4	13.8	6	20.7	2	6.9	29	100	X
f. Unemployed	2	66.7	1	33.3	0	0.0	0	0.0	0	0.0	3	100	X
g. Other	5	21.7	15	65.3	3	13.0	0	0.0	0	0.0	23	100	X
Total or Average	1358	17.7	4224	54.8	1861	24.2	142	1.8	115	1.5	7700		

X = eliminate as not being statistically important.

for either of these
CHEMICAL PUMPING
needs . . . specify
ALDRICH

AUTOMATICALLY CONTROLLED DELIVERY

MEDIUM to HIGH PRESSURE SERVICE

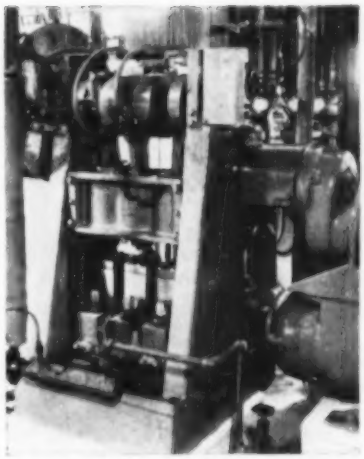
FOR AUTOMATICALLY CONTROLLED DELIVERY use an Aldrich-Groff "POWR-SAVR." This variable stroke triplex pump controls delivery from 0 to 100% of capacity at constant pump and motor speed . . . can be controlled from any remote point, manually or automatically. Power requirements are low, because consumption is directly proportional to demand.

"POWR-SAVR" pumps handle any free-flowing liquid at discharge pressures from 300 to 15,000 psi and are available in six sizes—from 2″ to 6″ stroke and from 5 to 125 bhp. For more information on these versatile pumps, write for Data Sheet 65.

FOR MEDIUM TO HIGH PRESSURE SERVICE several types of constant stroke pumps are available—depending upon the service involved. You may need the Inverted Vertical Triplex (Data Sheet 66), the Vertical Triplex (Data Sheet 26), or the Direct Flow Triplex or Multiplex Pump (Data Sheets 64, 64B). (All these helpful data sheets are available upon request.)

From our experience in building pumps for the chemical industry, we can—from our engineering and service files—frequently make specific recommendations to meet your chemical pumping needs. Whatever your problem, we welcome your inquiries.

Aldrich Pumps are ideal for applications involving corrosion, abrasive materials, high viscosity or high pressure. Among many liquids handled by Aldrich Pumps are: caustic solutions, fatty acids, nitric acid, acetic acid, aqua ammonia, anhydrous ammonia, as well as liquids encountered in the petroleum refining, petroleum chemical, and other industries.

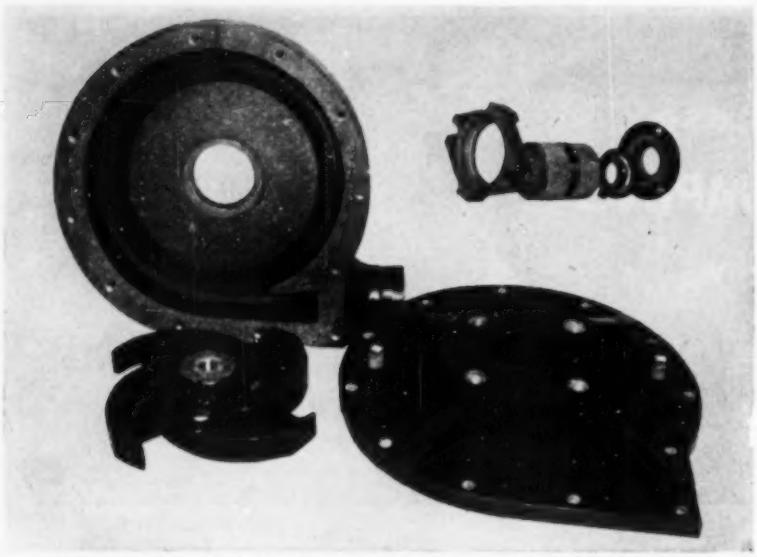


This Aldrich Vertical Triplex Pump—on the job at the Burlington, N. J., plant of Hercules Powder Company—is employed to pump rosin ester in the manufacture of Abitol, hydroabietyl alcohol, used in lubricants and in the manufacture of alkyd resins. In this application pump capacity is one gallon per minute against 6,000 pounds discharge pressure.

THE ALDRICH PUMP COMPANY
20 GORDON STREET • ALLENTOWN, PENNSYLVANIA

...Originators of the Direct Flow Pump

Representatives: Birmingham • Bolivar, N. Y. • Boston • Buffalo • Charleston, W. V. • Chicago • Cincinnati • Cleveland • Denver • Detroit Duluth • Houston • Logansport, Ind. • Los Angeles • New York • Omaha • Philadelphia • Pittsburgh • Portland, Ore. • Richmond, Va. Salt Lake City • St. Louis • San Francisco • Seattle • Spokane, Wash. • Syracuse • Tulsa • Youngstown



THESE MOLDED HAVEG PARTS ARE USED IN PUMPS FOR HOT (104° F.) 30% HYDROCHLORIC ACID
TYPICAL SERVICE RECORD: 33 MONTHS WITHOUT REPLACING A SINGLE PUMP PART.

WHERE PUMPS MEET HOT CORROSIVES
USE HAVEG

In the design of pumps for handling highly corrosive liquids, Haveg engineers have successfully recommended the use of Haveg for many parts in contact with the liquid. Such parts include the casing, suction head, impeller, mechanical seal, seal ring, bushing clamp, shaft sleeve, back-up ring, drip pan . . . and any other part that must be 100% corrosion-resistant.

Haveg is a moldable, thermosetting plastic material made of acid-digested asbestos and special resins. Haveg effectively resists most acids, salts, chlorine, many solvents—even when used continuously in temperatures as high as 265° F. with a good margin of safety. Haveg is physically strong and is extremely resistant to thermal shock. Haveg is smooth-molded and is easily machined with standard tools.

If you manufacture pumps, valves, and related equipment . . . or if you're looking for the most effective corrosion-resistant tanks, towers, heat exchangers, and other process equipment, call in a Haveg sales engineer for technical assistance. Send for 64-page Bulletin F-6; contains complete engineering data on Haveg.

PUMPS TANKS PIPE

HAVEG CORPORATION*
NEWARK, DELAWARE
TRADE MARK REG. U. S. PAT. OFF.

Factory: Marshallton, Del. Wilmington 3-6884

ATLANTA Exchange 3821
CHICAGO 11 Delaware 7-6088
CINCINNATI 37 Valley 1610
CLEVELAND 20 Washington 1-8700
DETROIT 35 Broadway 3-0880
HARTFORD 5 Hartford 6-4250
HOUSTON 4 Jackson 6840
LOS ANGELES 14 Mutual 1105
SEATTLE 7 Hemlock 1351
ST. LOUIS 17 Hiland 1223

*A subsidiary of Continental-Diamond Fibre Co.
Is the Haveg Bulletin F-6 in your files? Write today!

NEWS

(*Continued from page 52*)

CORROSION-CONTROL HAZARDS MADE KNOWN

The Inter Society Corrosion Committee has recently expressed concern about the hazards that may result from dependence on certain unproved devices for controlling corrosion and scaling. It recommends that caution be exercised in the application of such devices, since any failure to give protection may result in serious damage to expensive equipment if a real problem of corrosion exists.

The Committee draws particular notice to devices that are not based on any understandable scientific principle and that generally are promoted on the basis of testimonials from presumably satisfied customers, unsupported by quantitative data. Special attention is drawn to supposedly scientific explanations which make liberal and incoherent use of such terms as *catalysis, magnetism, electronics, radiation*, etc.

In some cases manufacturers recommend that grounding wires be rearranged if desired. The Committee emphasizes that if circuits are not grounded in accordance with the National Electrical Code, serious safety hazards may result.

The Inter Society Corrosion Committee is made up of about thirty-five delegates from major technical societies in the United States and Canada, among them the A.I.Ch.E., actively concerned with problems of corrosion control.

SOLVENT EXTRACTION PROCESS

(*Continued from page 22*)

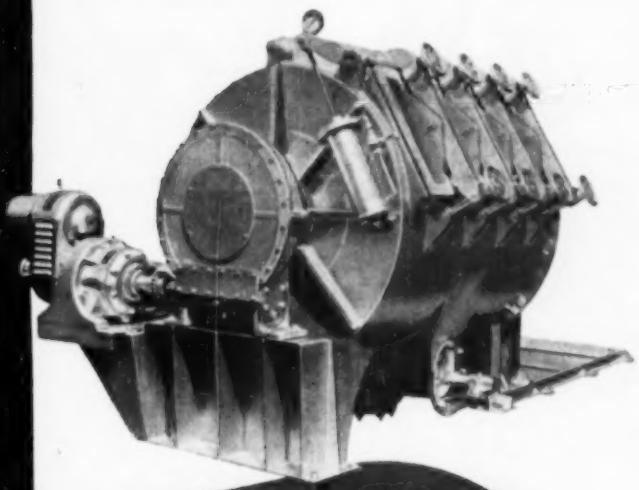
filter, it is explained, has been operated at a capacity up to 6 tons of cottonseed/day/sq. ft. of filter screen, or about 21 tons/day. For a capacity of 3 tons/day/sq. ft. of filter screen, the filter operates with a 2-in. cake at a pan speed of 2.5 to 3.5 rev./min. under a vacuum of 1 to 6 in. Hg.

Filtration extraction, Government engineers believe, can be adapted to many materials and thus make possible year-round operation when different oilseed raw materials are available. The process is expected to prove successful with peanuts, flaxseed, and sesame. Another advantage stressed is economy; in older processes only cottonseed processing requires prepressing, and therefore this equipment would be idle when plants used soybeans, rice bran, and other raw materials. Filtration extraction eliminates the need for prepressing.

(*More News on page 58*)

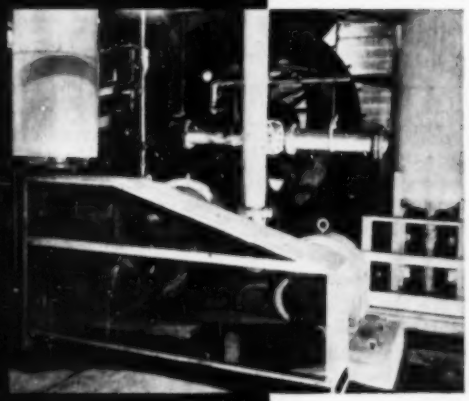
dependable process equipment built to fit your needs

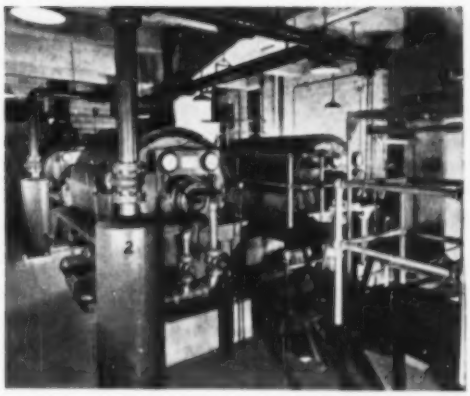
Conkey Rotary Leaf Pressure Filters; a preeminent type for clarification filtration, builds a cake, washes out solubles, dewaters and discharges the cake, all without necessity for opening up of the filter.



CONKEY FILTERS
FOR CHEMICAL PLANTS

Conkey Rotary Hopper Vacuum Dewaterers, high capacity top feed vacuum filters for fast filtering and rapidly segregating slurries, require no adjustments for feed variations in consistency and particle size.





Conkey Sludge Filters automatically dewater industrial waste sludges at high capacity rates with resultant low cake moistures.

PROCESS EQUIPMENT DIVISION GENERAL AMERICAN

Process Equipment Division

Send for latest bulletin on Filters

GENERAL AMERICAN TRANSPORTATION CORPORATION

Sales Office: 380 Madison Avenue, New York 17, New York
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Other General American Equipment: Turbo-Mixers • Evaporators • Dewaterers Towers • Tanks • Dryers • Pressure Vessels

easy does it...
with
DOW CORNING
ANTIFOAM A

Optimum concentrations of Dow Corning Antifoam A against a wide variety of foamers are so small they are measured in parts per million. For instance:

4 p.p.m. (0.0004%) defoams cottonseed oil
1 p.p.m. (0.0001%) defoams fermenting wheat
1 p.p.m. (0.0001%) defoams neoprene latex
1 p.p.m. (0.0001%) defoams paper sizing
.02 p.p.m (0.000002%) defoams vat dies

Used throughout the processing industry, Dow Corning Antifoam A cuts processing time; increases productive capacity; eliminates waste and hazardous overflow.

Odorless, tasteless and nontoxic, Antifoam A is safe, swift and by far the most economical defoamer you can buy.

DOW CORNING ANTIFOAM AF EMULSION.

Originally developed for use in the food industry, this new water-dispersible silicone emulsion is equally versatile, equally effective in industrial processing of aqueous foamers.

For further information on these materials, we invite you to . . .

see for yourself!

Mail coupon today for FREE SAMPLE

DOW CORNING SILICONES

Dow Corning Corporation
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Please send me data and a free sample of—
☐ Dow Corning Antifoam A or
☐ Dow Corning Antifoam AF Emulsion

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COMPANY _____
ADDRESS _____
CITY _____ ZONE _____ STATE _____

NEW PLASTIC TANK TRANSPORTS CHEMICALS

A 3,400-gal. reinforced plastic transport tank for trucking formaldehyde, acetic acid, alcohols, and similar liquid chemicals was exhibited last month. Made of American Cyanamid Co. Laminac polyester resin and fibrous-glass reinforcement, the tank is one of the largest one-piece molded structures ever made, according to the company. It measures 21 ft., 9 in. long; 6 ft., 2 in. wide; and 4 ft., 4 in. high unmounted The tank was manufactured over a wood mold; the resin was sprayed on, then layers of glass mat were added, and a specially catalyzed resin was spread over each layer.

Unlike steel tanks, with which it is designed to compete, the plastic tank requires no special lining. Also, as emphasized by John A. Roberts, vice-president of P. B. Mutrie Motor Transportation, Inc., operators of the transport, the reinforced plastic is highly resistant to corrosion, and leaks can be inexpensively patched with resin and glass.

The oval-shaped tank when fully equipped and mounted on the trailer weighs 7,025 lb., 3,600 lb. less than a similar steel tank. "We estimate," said Mr. Roberts, "that on a run between Springfield, Mass., and Montreal, for instance, the tank will increase our payload $32.28 per run without exceeding the 50,000-lb. over-the-road limit. Based on two loads per week between these two points, the yearly increase is $3,357.12."

The tank, molded by Carl N. Beetle Plastics Corp., is fitted to a trailer chassis specially designed and built by Fruehauf Trailer Co. and is pulled by a Mack Motor Truck Corp. tractor. Special dent-resistant fenders and the hose and pump compartments are made of the same plastic-glass combination as the tank.

In testing, the tank was filled with 27,430 lb. of water and measured for strain resistance by gauges and accelerometers attached to its surface. The chassis was twisted, and the truck was raced over rough and smooth roads. During the tests the highest bending stress reached was 840 lb./sq. in.; the breaking point of the material is 20,000.

FAT-SPLITTING PROCESS FOR SMALL PLANTS

A package-type plant that makes modern continuous fat splitting practical for the small processor has been designed by the Blaw-Knox Co. Using the Colgate-Emery process, the new plant has a rated capacity of 500 lb./hr. and offers the high yields (up to 98 per cent) of quality products and the low operating costs previously available only in larger units with capacities ranging from 1,500 to 7,500 lb./hr.

For nearly a century fat splitting had been a batch operation, and for about fifty years a catalyst had been used to speed hydrolysis. The Colgate-Emery process, in operation since 1947, makes it possible, according to Blaw-Knox engineers, to eliminate the catalyst, and it has the advantage of continuous countercurrent reaction.

NICKEL MADE OXIDATION RESISTANT

A new ceramic coating for commercial nickel may permit the use of nickel in jet engines, gas turbines, guided missiles, and other high-temperature devices, according to an announcement of the Oak Ridge National Laboratory, Oak Ridge, Tenn. Nickel, a refractory metal with excellent thermal conductivity characteristics, has hitherto been limited in use because of its poor resistance to oxidation.

The new coating process anneals nickel specimens in water-saturated hydrogen at 1,000° F., sprays them with a ceramic coating, and dries and fires them. The use of wet hydrogen in the annealing produces a durable coating; dry hydrogen produces bubbly surface condition. Durability of coating was tested by heating in an oxidizing atmosphere at 1,500° F. for 65 hours.

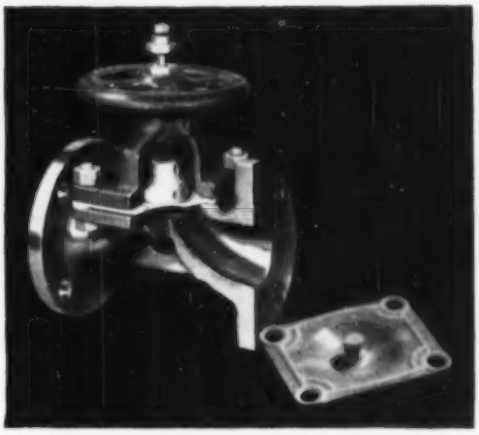
HILLS-McCANNA

CORROSION RESISTANT VALVING
DATA SHEET

New Data on TEFLON* Diaphragms for Hills-McCanna Saunders Patent Valves

Solid unplasticized TEFLON sets new performance standards in previously tough services

HILLS-McCANNA'S introduction of the first Teflon diaphragm early this year made the advantages of the Saunders Patent Valve available for the first time in the valving of many extremely hard-to-handle fluids. The Hills-McCanna Teflon diaphragm is solid Teflon. No plasticizer is used so there is no impairment of inert Teflon's qualities or uniformity. The Teflon is not combined with any other material, not even the customary metal stud previously used to attach diaphragms. As a diaphragm, Teflon will handle temperatures to 400°F., pressures to 100 psi. This, coupled with Teflon's well known chemical resistance, makes possible satisfactory valving of virtually any concentration of mineral or organic acids; alkalies; alcohols such as aliphatic and aromatic, phenol, cresol; aliphatic, aromatic and chlorinated industrial solvents and many others.



Cutaway view of a Teflon diaphragm equipped Hills-McCanna Valve and a Teflon diaphragm. These valves are available with a wide choice of manual, remote and automatic operators. Valve bodies of cast iron or any machinable alloy or with lead, glass, rubber, plastic, etc. linings. For hazardous services special models with Teflon stuffing boxes are available.

Performance proved in a wide variety of installations

Pharmaceutical — Nitration, animation, chlorination and sulfonation reactions handled up to 100 psi, 400°F.

Oil, Soap and Fat — Oleum, sulfuric acid, sulfonyl chloride and alkyl and aryl sulfonates handled successfully.

Antibiotic — Successfully used in solvent extraction service combining asceptic qualities with acid resistance of glass lining and packless construction.

Petrochemical — Provides complete resistance to chlorine sulfonation reagents and all types of chlorinated hydrocarbons.

Paint and Varnish — Successfully handling solvents.

Fertilizer — Offers complete resistance to low pressure ammonia and urea-ammonia solutions with no stuffing box required.

Textile — Provides complete resistance to scouring, emulsifying, dispersing, sizing and kier reagents without stuffing box.

Leather Processing — Successfully handling surface active agents, finishing agents and compositions.

Write for additional reports of service in your industry.

TEFLON diaphragms simplify chemicals manufacturing

Mineral acids — sulfuric, nitric, hydrochloric, chromic — successfully handled in any concentration of 100 psi, 400°F.

Organic acids — formic, acetic, oxalic, thioglycolic, benzoic — handled at pressures to 100 psi, temperatures to 400°F.

Alkalies — sodium hydroxide, potassium hydroxide, ammonium hydroxide — successfully handled to 100 psi, 400°F.

Aliphatic and aromatic alcohols — phenol, cresol — handled at pressures to 100 psi, temperatures to 400°F.

Aliphatic, aromatic, chlorinated industrial solvents — carbon disulphide, carbon tetrachloride, etc. — handled at pressures to 100 psi, temperatures to 400°F.

FOR FURTHER INFORMATION
Write, wire or phone:
HILLS-McCANNA CO.
2438 W. Nelson Street
Chicago 18, Illinois

*Registered DuPont Trademark for Tetrafluoroethylene resin. As used in the Hills-McCanna diaphragm it is solid non-lubricated (non plasticized) Teflon.

PLA-TANK DUCTS

are the answer where corrosion is a problem

PLA-TANK DUCTS

are manufactured from long-life resin-bonded glass fiber.

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are resistant to a wide variety of fumes.

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are resistant, inside and out, at temperatures from -60° F. to 280° F.

PLA-TANK DUCTS

are competitively priced with other corrosion-resistant materials.

PLA-TANK DUCTS

are available now in standard 6"—54", as well as rectangular and custom-built shapes, including hoods.

PLA-TANK DUCTS

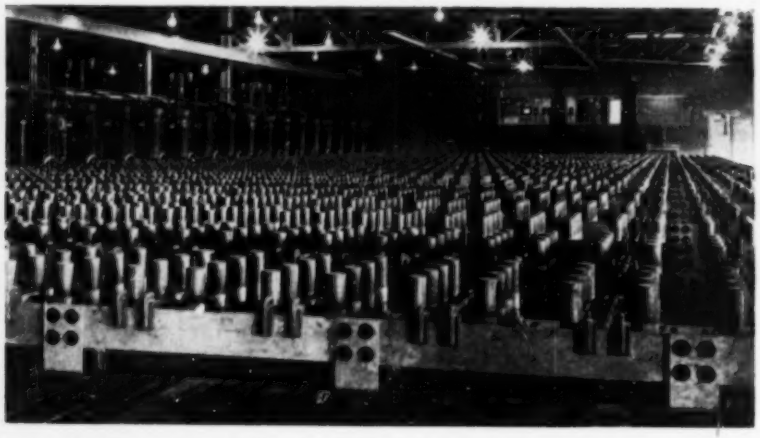
are the answer to your needs for many fume exhaust jobs now on your drawing boards —or for replacements in existing systems.

Write for free data file sheet

THE *Chemical* CORPORATION

73 Waltham Ave., Springfield 9, Mass.

PENNSALT USES DENORA CELLS IN NEW PLANT



The new chlor-caustic plant erected by the Pennsylvania Salt Mfg. Co. at Calvert City, Ky., employs DeNora mercury amalgam electrolytic cells, each cell having a rating of 30,000 amp. The plant has a rated capacity of 50 tons of chlorine and a proportionate amount of caustic soda and hydrogen a day. Amalgam decomposers are at the left in the photograph; the rectifier and cell-control room can be seen through the window at the rear.

NEW AMMONIA PLANT FOR ILLINOIS

A plant for the production of synthetic ammonia and fertilizer nitrogen compounds will be built at Tuscola, Ill., National Distillers Products Corp. announced recently. Expected to be completed by January, 1955, the $7 million plant will have an annual production capacity of 50,000 tons of anhydrous ammonia. Part of the ammonia will be converted into nitric acid, which will be transformed into ammonium nitrate by reaction with more ammonia. In turn the ammonium nitrate will be used in the manufacture of nitrogen solutions.

Nitrogen will be obtained by liquefying air to separate the oxygen from the air. By-product oxygen from this plant will amount to 75 tons a day. Hydrogen is usually obtained by decomposition of natural gas by any one of a variety of processes. The National Distillers plant, however, will obtain hydrogen ready-made as a by-product of National Petrochemicals Corp.'s ethylene plant also under construction at Tuscola.

AID TO VISITING ENGINEERS PLANNED

The Office of International Relations of the National Research Council, National Academy of Sciences, recently announced a plan for establishing regional international-relations centers for engineers and scientists. The first to be opened, sometime this fall, will be in San Francisco and will be operated by the Cooperative Research Foundation.

The main functions of the center will be to facilitate contacts between visiting engineers and scientists and those in the area; to serve as a coordinating agency for international scientific personnel in the area; and to offer assistance that other institutions of the area may not be equipped to give.

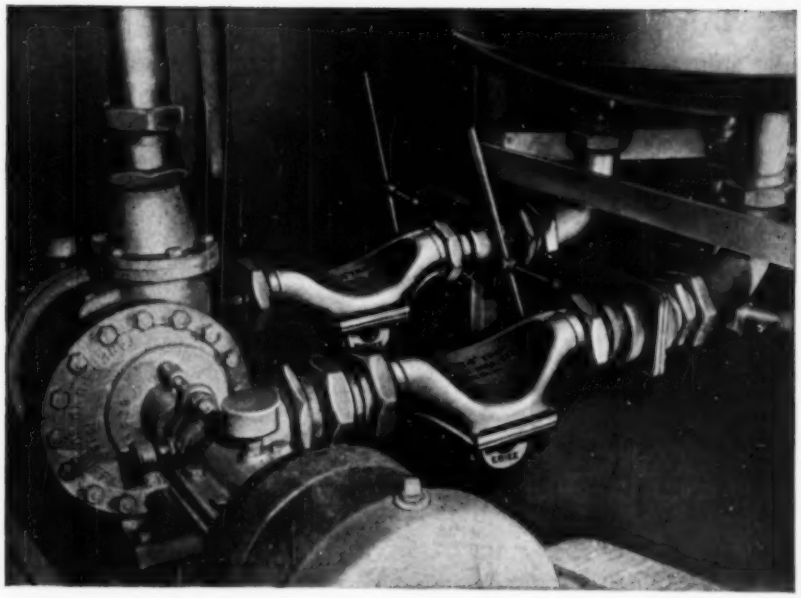
MERCURIC ACETATE MADE FROM MERCURY

A new method of making mercuric acetate directly from mercury has been developed by Buffalo Electro-Chemical Co. Because of the poor reactivity of mercury with acetic acid, mercuric acetate has until now been made with various mercury salts, which are relatively expensive.

F. P. Greenspan of Buffalo Electro-Chemical has found that mercuric acetate can be made by treating metallic mercury with peracetic acid in a glacial acetic acid medium. The mercury will dissolve in peracetic acid, forming a precipitate of mercurous acetate, which is then converted, by heating in the presence of excess acetic acid, into the desired soluble mercuric acetate.

In this process commercial peracetic acid cannot be used because it is ordinarily prepared by a process involving the use of sulfuric acid, which catalyzes formation of the peracid. Residual sulfuric acid would give rise to certain amounts of undesirable insoluble mercuric sulfate. Peracetic acid for this new process therefore is preferably made with nitric acid as a catalyst, the company explained.

(More News on page 62)



ERIEZ MAGNETIC PIPELINE TRAPS, widely used in the process industries, provide the superior magnetic strength of a high nickel alloy . . . ALNICO . . . to assure positive trapping of tramp iron. Housings are non-magnetic chromium-nickel stainless steel castings . . . leak-proof, easy to install and simple to clean. Completely non-electric . . . first cost is last cost . . . since magnets hold strength during life of equipment.

1,045 PIECES OF TRAMP IRON REMOVED ahead of vane-type displacement pump in food production line during a 30-day period, by an ERIEZ Permanent (non-electric) Magnetic Pipeline Trap.

Prevent

→ ***Machinery Damage***

→ ***Product Contamination***

→ ***Production Tie-Ups***

...Automatically, with Eriez Magnetic Traps

Look at this pile of tramp iron...

Trapped ahead of a pump in a large food plant during a 30-day processing period... it exemplifies how "protection plus" is obtained automatically with pipeline traps produced by ERIEZ MANUFACTURING COMPANY, Erie, Pa.

To keep liquid flow lines free of ferrous materials ranging in size from minute particles to large pieces of tramp iron, ERIEZ pipeline traps utilize the strong magnetic properties of Alnico permanent magnets containing a high percentage of nickel.

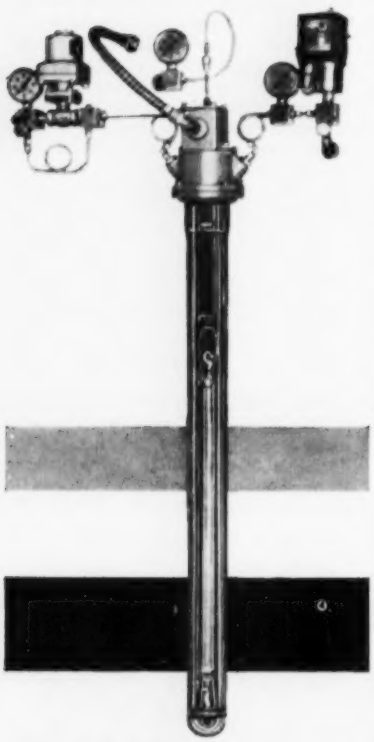
Use of this aluminum-nickel-cobalt-iron alloy not only permits trap designs that eliminate need for electromagnets requiring current and accessory equipment, but its use also allows reduction of space and weight requirements to desirable limits.

The addition of nickel... an essential in Alnico ...improves scores of other alloys utilized throughout industry. Consult us on use of nickel or nickel alloys in your products or equipment.

Send details of your metal problems for our suggestions.

At the present time, nickel is available for end uses in defense and defense supporting industries. The remainder of the supply is available for some civilian applications and governmental stockpiling.

THE INTERNATIONAL NICKEL COMPANY, INC. 67 WALL STREET NEW YORK 5, N. Y.



ACTINIC RADIATION *for* PHOTOCHEMISTRY

Compact photochemical equipment for continuous flow, batch or recycling processes is well recognized for volume production. Hanovia lamps offer many distinct advantages and, frequently, economies over other techniques for achieving identical reactions.

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1630

NEWS

(*Continued from page 60*)

A.E.C. AWARDS RESEARCH CONTRACTS

The U. S. Atomic Energy Commission announces the award of nearly fifty unclassified one-year physical-research contracts to universities and private research institutions in accordance with its policy of utilizing private facilities for research related to atomic energy. Usually the institution contributes the funds and services which it would normally devote to such work, and the A.E.C. provides funds for equipment and for salaries of research associates and assistants.

Among the awards made are the following: $7,450 to Alfred University for graphitization of carbon; $24,500 to Armour Research Foundation for the system zirconium-nitrogen; $10,467 to University of California at Los Angeles for nuclear chemistry research; $11,363 to University of California at Berkeley for studies in intermolecular forces and solubility; $25,000 to Case Institute of Technology for scaling of zirconium in air at elevated temperatures; $10,363 to Catholic University of America for thermal production and identification of free radicals; $46,308 to University of Chicago for nuclear chemistry research and $55,956 for natural abundance of deuterium and other isotopes; $6,339 to Columbia University for thermodynamic properties of sodium vapor and $36,400 for chemical properties of fused electrolytes for zirconium preparation; $5,360 to Cornell University for structure of fluorocarbons, elementary boron, and boron compounds; $67,060 to Horizons, Inc., for process development for production of thorium metal; $9,270 to Indiana University for studies with radioactive tracers; $34,111 to State University of Iowa for separation of gases by diffusion through permeable membranes; $18,800 to Johns Hopkins University for studies in nuclear chemistry; $3,000 to University of Louisville for the synthesis and properties of ion-exchange resins.

Further awards made by the Commission included $4,428 to Michigan State College for investigations into aperiodic oxidation states and $24,732 for a physico-chemical investigation of the interhalogen compounds; $165,880 to University of Notre Dame for radiation chemistry studies; $12,250 to University of Oregon for electrochemical and polarographic studies on the corrosion of zirconium in presence of various aqueous media; $4,500 to Purdue Research Foundation for metal ion chelate complexes and $5,000 for polarographic studies in nonaqueous solvents; $3,132 to University of Wisconsin for high frequency titrations, $7,000 for studies of rates and equilibria of inorganic reactions in solution, and $26,978 for application of radioactive tracers to chemical problems.

E. J. C. COUNSELS ARMY INDUCTEES

The Engineering Manpower Commission has called to the attention of young engineers about to enter the service the Army regulation providing for the identification and assignment of scientific and professional personnel who are qualified under the regulations to perform duties in research and development, construction, and related work.

Army Special Regulation 615-25-11 of Aug. 7, 1952, has as its objects to

1. Insure that military personnel who have had scientific and professional training are utilized in military duties related to their training to the greatest extent possible.
2. Make known to the Department of the Army information concerning availability of individuals qualified to meet immediate or future requirements for scientific and professional personnel on an Army wide basis.
3. Enable the development of a system for indicating requirements for scientific and professional personnel and for requisitioning such personnel.

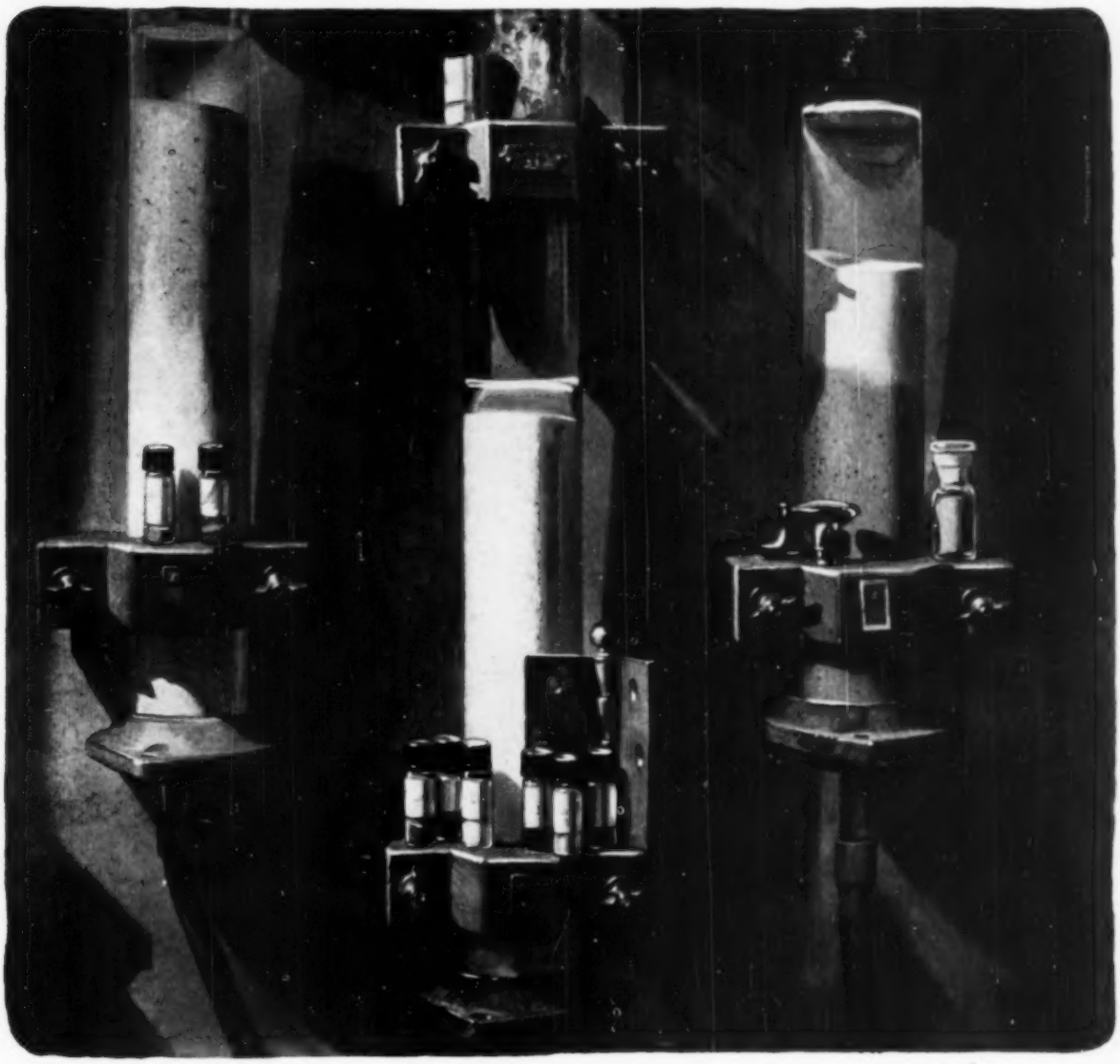
Each recruit in the Army is assigned a number known as his Military Occupational Specialty number (MOS). There are two broad categories of scientific and professional personnel, type A and type B. According to E. J. C., type A personnel have better opportunities for assignment to duties that will utilize their professional and scientific training than do type B.

Among the aids to classification of recruits the regulations list letters from civilian educational institutions and governmental and industrial organizations and a transcript of academic credits. Such documents, it is pointed out, should be in the possession of eligible recruits when they are inducted.

All the major engineering curricula are included in the scientific and professional personnel program, the E. J. C. states and adds that in addition to a specified score in an aptitude test a candidate must have a bachelor's degree in his field and usually at least one year's experience or a master's degree.

(*More News on page 64*)

DEPARTMENT OF LOST AND FOUND



For want of a suitable recovery process, tons of valuable metals are discharged to waste each year. At best, this means economic loss; at worst, stream pollution. **AMBERLITE** ion exchange—a process which finds needles in chemical haystacks—often can obviate both problems.

The columns shown here will interest users of copper. They show how **AMBERLITE**® **IRC-50**, a cation exchange resin, efficiently adsorbs copper from solutions of its salts. Another cation exchanger, **AMBERLITE IR-120**, helps the rayon industry by removing zinc from rinse water. The zinc is then re-used, and highly toxic wastes have been decontaminated.

There are many other examples: in electroplating, metal pickling, rare earth separations, and the processing of paper mill wastes. If your work involves such problems, or others in which dilute solutions of metallic salts occur, **AMBERLITE** ion exchange may offer you a new process, or a better one.

AMBER-HI-LITES, *a bi-monthly report on ion exchange, is available on request.*

ROHM & HAAS COMPANY

THE RESINOUS PRODUCTS DIVISION PHILADELPHIA 5, PENNSYLVANIA

Sharples has...

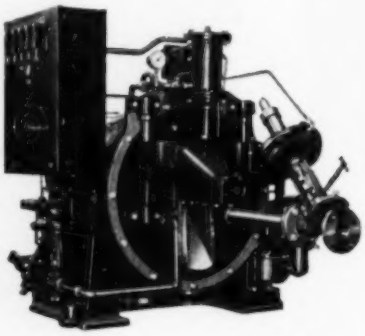
TWO RIGHT ANSWERS

for crystal dehydration

The proved answer to any crystal dehydration problem is found in one of these two Sharples centrifuges. An analysis of your particular requirements will lead to an unbiased recommendation as to the type of centrifuge most suitable—Sharples makes both.

IF YOU RINSE THE CRYSTALS

The Sharples Super-D-Hydrator is designed primarily for free draining crystals, where product purity or separation of the mother and rinse liquors are of critical importance. The continuous cyclic-operation may be easily controlled to adjust for any particular washing and drying conditions. Capacities on the larger C-27 model range up to 8 Tons per hour on some materials. Bulletin 1257 describes the Super-D-Hydrator



IF YOU DO NOT RINSE THE CRYSTALS

The Sharples Super-D-Canter is used for dehydrating fine or amorphous-type materials. Where washing efficiency and final moisture content are not critical, the Super-D-Canter has decided economic advantages in capacities up to 3,000 lbs. per hour. The rate of liquid handling is substantially independent of the crystal concentration, and the Super-D-Canter operates continuously and efficiently without regard to changes in slurry concentration. Write for Bulletin 1254.

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DR. ALFRED WHITE DIES

Dr. Alfred Holmes White, President of the Institute in 1929 and 1930, Vice-President in 1928 and Director in the years 1922 and 1923, died suddenly on Aug. 25, 1953, at Ann Arbor, Mich. He was 80 years old.

Professor White was elected to the membership of the Institute in 1914 and since that time has been deeply interested in Institute affairs. He served on the Chemical Engineering Education Committee of the Institute for many years and was active in the work of this committee prior to and during the early days of the Institute program of accreditation of chemical engineering curricula which started in 1925. It was the first engineering curriculum accrediting program in the United States.

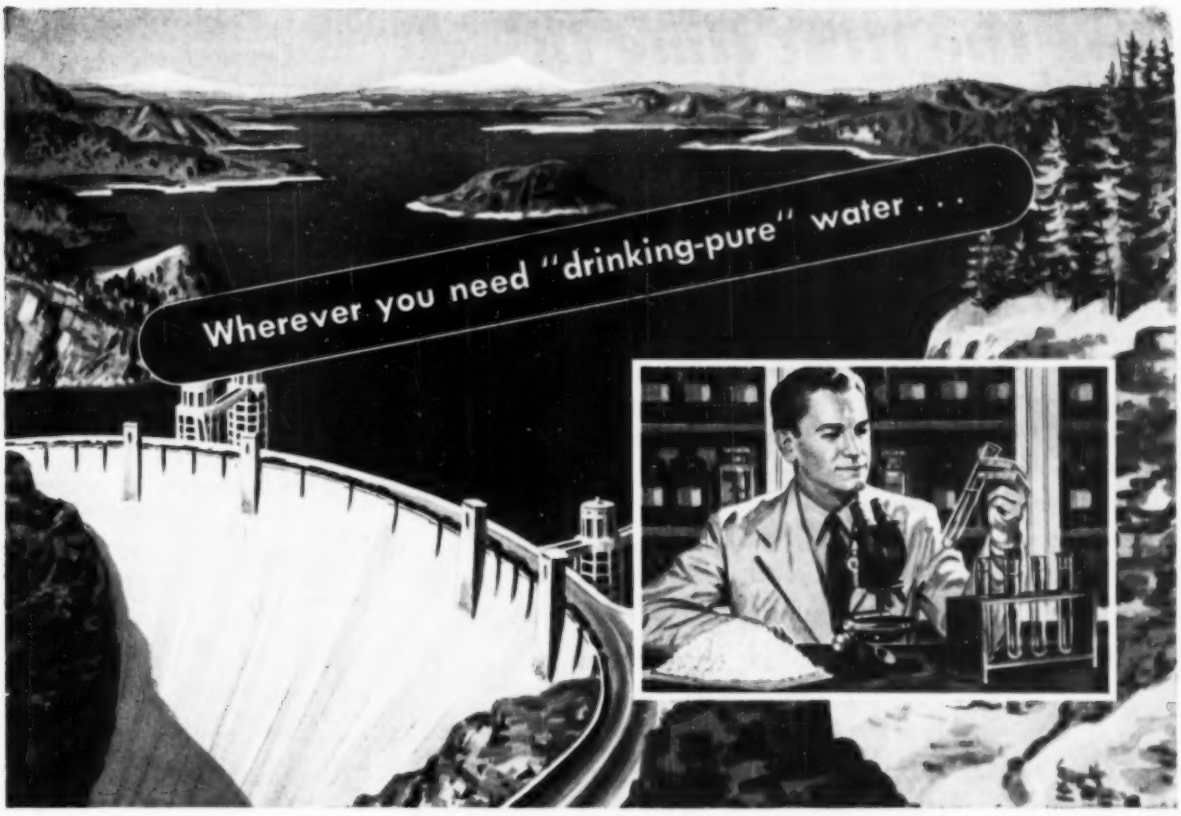
He founded the School of Chemical Engineering at the University of Michigan in 1914 and therefore was one of the first educators in the chemical engineering field. He was instrumental in the development of the chemical engineering curriculum as it stands today.

Dr. White was born in Peoria, Ill., April 29, 1873. His father before him was a teacher, being Principal of the Normal School at Peoria. The son received an A.B. degree from the University of Michigan in 1893. He was a student at the Federal Polytechnic School, Zurich, Switzerland, in 1896-1897 on leave of absence from the University of Illinois. During this period of study he specialized in chemical technology. On his return to this country he entered the University of Michigan and received his B.S. degree in 1904. He received an honorary degree of doctor of engineering from the University of Detroit in 1948. He has been Professor Emeritus of Chemical Engineering at the University of Michigan since May, 1943.

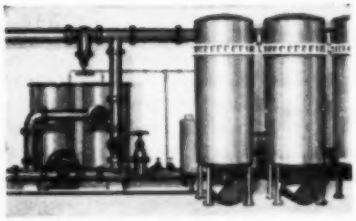
Professor White is well known for his many contributions to the general field of education.

During his career Professor White carried on research in the field of the fixation of nitrogen, pyrolysis of coal, application of oxygen to gas manufacture, purification of boiler feed water, stainless steel and volume changes in concrete.

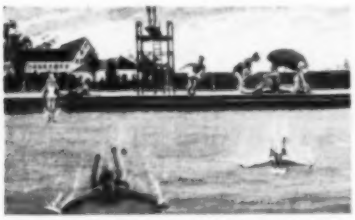
At the time of his death Dr. White was actively at work on the preparation of a book in the chemical engineering field.



CELITE FILTRATION produces clear sparkling water . . . even removes chlorine-resistant organisms



In municipal water works—engineers find that a Celite Diatomite Filtration System permits lower capital investment plus high operating efficiency. Filtration is extremely thorough, the filter cake can withstand many times the pressure of an ordinary filter bed. No pH control is necessary with Celite.



In swimming pools—operators find that Celite Filtration not only safeguards the purity of pool water, but it provides sparkling clear, inviting water—an important asset in attracting customers. With Celite Filtration, there is a continuous recycling of water at fast flow rates, and the need for chemical treatment is reduced.

Celite* Filtration removes even the finest suspended solids such as amoebae and algae—many of which cannot be filtered by other means. All these impurities are entrapped by Celite's almost infinite network of tiny porous particles . . . thus reducing the need for chemical treatment. Celite offers many other advantages, too . . . it permits important space savings in the installation, high flow rates are maintained, and far less backwash water is required for cleaning the system.

Carefully processed from the purest deposits of diatomaceous earth, Celite is available in nine standard grades. Each is designed to filter out suspended impurities of specific size and type. Utmost uniformity of product is maintained, so that whenever you reorder, you are assured of the same accurately graded powder.

Municipal water works engineers, food processors, beverage manufacturers, swimming pool operators . . . all who require "drinking-pure" water, can benefit from filtration with Celite Filter Aids. It will pay you to investigate the many advantages of Celite for your particular requirement! To have a Celite Filtration Engineer study your problem and offer recommendations, simply write Johns-Manville, Box 60, New York 16, New York. In Canada, 199 Bay Street, Toronto 1, Ontario. No obligation or cost.

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*T.M. Reg. U. S. Pat. Off.

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24TH EXPOSITION of CHEMICAL INDUSTRIES

ESTABLISHED 1915

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COMMERCIAL MUSEUM AND CONVENTION HALL

See almost 500 exhibits conveniently located on one floor, representing all phases of the chemical industries. Chemical engineers, chemists and skilled technical men will be on hand to offer the latest information and practical solutions to your processing production problems. See and compare, methods, materials, equipment, processes and techniques that will affect future trends in the chemical processing industries.

Acquire in a matter of days factual information it would take you months to accumulate. For 38 years this great exposition has exerted a vital progressive influence in the increasingly important field of chemical processing. PLAN NOW TO ATTEND.

Application forms for hotel accomodations are available by writing to

INTERNATIONAL EXPOSITION COMPANY • 480 LEXINGTON AVENUE, NEW YORK 17, N. Y.

NEWS

(*Continued from page 64*)

CREATIVENESS IS THEME OF JOINT MEETING

The joint meeting of the American Society for Engineering Education and the Engineers' Council for Professional Development, to be held from Oct. 14 to 17 at the Statler Hotel, New York, will have as its theme "Civilization Is Dependent upon the Growth of the Engineering Profession."

Engineers and those employing engineers or counseling young men on engineering careers are welcome to the general meetings, which will be held on Thursday and Friday, Oct. 15 and 16. On Thursday creativeness in the arts and creativeness in engineering will be topics of discussion, and engineering education and manpower utilization will be the topics of Friday's meetings. On Friday also the annual Engineers Dinner will be held at seven o'clock. Horace P. Liversidge, chairman of the board of the Philadelphia Electric Co., will speak on industry and engineering education. Details of the program may be secured from the Secretary, A.I.Ch.E., or from Engineers Joint Council, 29 West 39 Street, New York 18, N. Y.

RADIOISOTOPES COURSES OFFERED AT OAK RIDGE

Three courses in the techniques of using radioisotopes in industrial research will be offered at Oak Ridge, Tenn., this winter. They are designed to enable mature research personnel to obtain in four weeks sufficient facility in the use of radioisotopes to apply them safely and efficiently to their own research problems. Preference will be given to university faculty members, group leaders of research teams, and other individuals who will impart the training to additional people.

The courses will start on January 4, February 8, and March 15, 1954. Applications and supporting letters must be submitted three months in advance of the starting date. Applications and information may be obtained from the Special Training Division, Oak Ridge Institute of Nuclear Studies, P. O. Box 117, Oak Ridge, Tenn.

GLASSED STEEL TANK TO STORE NITRIC ACID

The first glassed stainless-steel tank designed for storing fuming nitric acid is being produced by the Pfaudler Co., Rochester, N. Y., for the Holloman Air Force Base at Alamogordo, N. M. The company states that the new tank will eliminate the danger of explosion.

FULBRIGHT REQUESTS FOR CHEMICAL ENGINEERS

The Conference Board of Associated Research Councils has announced several requests for chemical engineers in the program of university lecturing and advanced research of U. S. Government Grants under the Fulbright Act for the academic year 1954-1955.

The Department of Industrial Chemistry of the Milan Polytechnic Institute wishes lectures by an American specialist having wide theoretical and experimental knowledge of the fundamental chemical processes with particular regard to their kinetic and thermodynamic aspects. The recipient would be invited to lecture on polymerizations and chemical-physical and technological tests, and to hold one or two seminars on subjects agreed upon in consultation with the other science departments of the university. The second semester might be spent at the University of Turin. Knowledge of Italian is not essential but would prove helpful.

The Institut Francais du Petrole, Paris, and the Institut du Genie Chimique, Toulouse, specifically request one lecturer for the former and a younger lecturer for the institutes in Nancy and Toulouse. Courses, direct laboratory work, and advice about installation of equipment for the study of chemical engineering are desired. Fluency in French is necessary.

A number of opportunities for research scholars are also listed. Fifty awards will be made for Germany, where engineering of all kinds is listed as a field of interest; the Netherlands, which will have up to four awards, lists engineering as a field in which American research scholars might work profitably; and the United Kingdom, with twenty awards, offers opportunities in almost every academic field.

Application forms may be obtained from the Committee on International Exchange of Persons, Conference Board of Associated Research Councils, 2101 Constitution Avenue, N.W. Washington 25, D. C.

EXCHANGE PROGRAM AT U. OF MINNESOTA

A series of seminars for graduate students and industrial personnel on aspects of classical and modern thermodynamics will be offered at the University of Minnesota this fall by K. G. Denbigh of the department of chemical engineering, Cambridge University. These seminars are part of an exchange program in the department of chemical engineering and are largely supported by the Minnesota Mining and Manufacturing Co.

BAKER PERKINS mixers will thoroughly mix and knead almost any material for the chemical processing industry

There is a BAKER PERKINS Mixer built to efficiently mix and knead materials ranging in consistency from dry powders and light fluids to stiff plastic masses. Close clearance between the blades and trough keeps every particle of the material in constant motion so that no part of the batch escapes the thorough mixing action of the blades. Intensive kneading is maintained as the material is pulled and squeezed against the blades, saddle and sidewalls. Consult a B-P sales engineer for full facts.

Size 16, NEM B P "Universal" Mixing and Kneading Machine for heavy plastic masses. Working capacity 150 gallons; total capacity 225 gallons. Fabricated steel trough shell jacketed for 150 psi. steam or water pressure. Cast iron trough ends are not jacketed. Saddle section has thermocouple for temperature control. Cast steel Sigma or Double Naben blades cored for circulating steam or water. Oil tight gear guards; anti-friction bearings. 50 HP motor.

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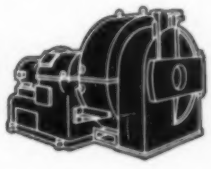
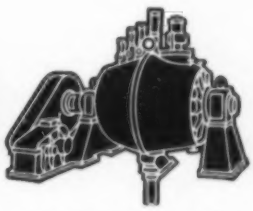


CENTRIFUGALS



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FUTURE MEETINGS AND SYMPOSIA OF A.I.Ch.E.

Chairman of the A.I.Ch.E. Program Committee

Loren P. Scoville, Jefferson Chemical Company, Inc. 260 Madison Ave., New York 16, N. Y.

MEETINGS

Annual—St. Louis, Mo., Hotel Jefferson, Dec. 13-16, 1953.

TECHNICAL PROGRAM CHAIRMAN: J. J. Healy, Jr., Assist. to V. P., Monsanto Chemical Co., 1700 S. 2nd St., St. Louis 4, Mo.

Washington, D. C., Statler Hotel, March 8-10, 1954.

TECHNICAL PROGRAM CHAIRMAN: George Armistead, Jr., Consult. Chem. Eng., George Armistead & Co., 1200 18th St. N.W., Washington 6, D. C.

Springfield, Mass., Hotel Kimball, May 16-19, 1954.

TECHNICAL PROGRAM CHAIRMAN: E. B. Fitch, Asst. to Res. Dir., The Dorr Co., Westport, Conn.

Ann Arbor, Mich., Univ. of Mich., Ann Arbor, Mich., June 20-25, 1954—Conference on Nuclear Engineering.

TECHNICAL PROGRAM CHAIRMAN: D. L. Katz, chairman, Dept. of Chem. and Met. Eng., Univ. of Mich., 2028 E. Eng. Bldg., Ann Arbor, Mich.

Glenwood Springs, Colo., Hotel Colorado, Sept. 12-15, 1954.

TECHNICAL PROGRAM CHAIRMAN: Prof. C. H. Prien, Dept. of Chem. Eng., Univ. of Denver, Denver 10, Colo.

Annual—New York, N. Y., Statler Hotel, Dec. 12-15, 1954.

TECHNICAL PROGRAM CHAIRMAN: G. T. Skaperdas, Assoc. Dir., Chem. Eng. Dept., M. W. Kellogg Co., 225 5Broadway, N. Y. 7, N. Y.

ASST. CHAIRMAN: N. Morash, Titanium Div., National Lead Co., P. O. Box 58, South Amboy, N. J.

Louisville, Ky., March 20–23, 1955.

TECHNICAL PROGRAM CHAIRMAN: R. M. Reed, Tech. Dir., Gas Proc. Div.. The Girdler Corp., Louisville 1, Ky.

Houston, Texas, May, 1955.

TECHNICAL PROGRAM CHAIRMAN: J. L. Franklin, Res. Assoc., Humble Oil & Refining Co., P. O. Box 1111, Bayytown, Texas.

Lake Placid, N. Y., Lake Placid Club, Sept. 25-28, 1955.

TECHNICAL PROGRAM CHAIRMAN: L. J. Coulthurst, Chief Proc. Designer, Foster Wheeler Corp., 165 Broadway, New York 6, N. Y.

Detroit, Mich.—Statler Hotel, Nov. 27-30, 1955.

TECHNICAL PROGRAM CHAIRMAN: T. J. Carron, Head, Chemical Tech. Office, Ethyl Corp., Res. Labs., 1600 West Eight Mile Road, Detroit 20, Mich.

SYMPOSIA

SYMPOSIA FOR ST. LOUIS MEETING

Distillation

Dust and Mist Collection

Drying

Use of Computers in Chemical Engineering

Heat Transfer

Carbonization

Industrial Waste Disposal

Mixing

CHAIRMAN: J. H. Rushton, Dept. of Chem. Eng., Illinois Inst. of Tech., Chicago, Ill.

MEETING—Washington, D. C.

Patents

CHAIRMAN: W. C. Asbury, V. P., Std. Oil Dev. Co., 15 W. 51st St., New York 19, N. Y.

MEETING—Washington, D. C.

Chemical Engineering in the Fertilizer Industry

CHAIRMAN: G. L. Bridger, Head, Dept. Chem. & Mining Eng., Iowa State College, Ames, Iowa.

MEETING—Washington, D. C.

Liquid Entrainment and Its Control

CHAIRMAN: H. E. O'Connell, Ethyl Corp., P. O. Box 341, Baton Rouge, La.

MEETING—Washington, D. C.

Chemical Engineering Fundamentals

CHAIRMAN: R. A. Kinckiner, E. I. duPont deNemours & Co., Wilmington, Del.

MEETING—Washington, D. C.

New Metal Technology

CHAIRMAN: W. C. Schroeder, U. S. Bureau of Mines, Dept. of the Interior, Washington 25, D. C.

MEETING—Washington, D. C.

Polymeric Materials of Construction

CHAIRMAN: C. C. Winding, Assist. Dir., College of Eng., Cornell Univ., Ithaca, New York.

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CHAIRMAN: D. L. Katz, Chairman (Address: See Ann Arbor Meeting).

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Submitting Papers

Members and nonmembers of the A.I.Ch.E. who wish to present papers at scheduled meetings of the Institute should follow the following procedure.

First, write to the Secretary of the A.I.Ch.E., Mr. S. L. Tyler, American Institute of Chemical Engineers, 120 East 41st Street, New York, requesting three copies of the form "Proposal to Present a Paper Before the American Institute of Chemical Engineers." Complete these forms and send one copy to the Technical Program Chairman of the meeting for which the paper is intended, one copy to the Chairman of the A.I.Ch.E., Program Committee, address at the top of this page, and one copy to the Editor of Chemical Engineering Progress, Mr. F. J. Van Antwerpen, 120 East 41st Street, New York.

If you wish to present the paper at a particular symposium, one copy of the form should go to the Chairman of the symposium instead of the Technical Program Chairman of the meeting.

Before Writing the Paper

Before beginning to write your paper you should obtain from the meeting Chairman, or from the office of the Secretary of the A.I.Ch.E., at 120 East 41st St., New York, a copy of the A.I.Ch.E. Guide to Authors, and Guide to Speakers. These cover the essentials required for submission of papers to the A.I.Ch.E. or its magazines.

Copies of Manuscript

Five copies of each manuscript must be prepared. For meetings, one should be sent to the Chairman of the symposium, and one to the Technical Program Chairman of the meeting at which the symposium is scheduled. If no symposium is involved, the two copies should be sent to the Technical Program Chairman. The other copies should be sent to the Editor's office since manuscripts are automatically considered for publication in Chemical Engineering Progress, or the symposium series of Chemical Engineering Progress, but presentation at a meeting is no guarantee that they will be accepted.

DEADLINE DATES FOR PAPERS

ST. LOUIS MEETING—(Passed)
WASHINGTON, D. C. MEETING—November 8, 1953
SPRINGFIELD MEETING—January 9, 1954
ANN ARBOR MEETING—February 15, 1954
GLENWOOD SPRINGS MEETING—May 12, 1954
NEW YORK MEETING—August 12, 1954
LOUISVILLE MEETING—November 20, 1954
HOUSTON MEETING—definite dates have not been set.
LAKE PLACID MEETING—May 25, 1955
DETROIT MEETING—July 27, 1955

MARGINAL NOTES

(*Continued from page 31*)

$$W = AX^aY^bZ^c$$

is to take logarithms. Admittedly, a linear relation in the constants is obtained in this way but it is not pointed out that there is no guarantee that the values for the constants so obtained are those for the given-type equation of the best fit to the experimental data.

Rao's book can be recommended as a reference for summarizing many useful statistical methods but not as a text for the chemical engineer beginning to study in this field.

The 3-F Club

Chemivision. From Farm to Factory to Fortune. William J. Hale. Destiny Publishers, Haverhill, Mass. (1952). 207 pp., $3.00.

Reviewed by Philip H. Groggins, Consultant, Washington, D. C.

In the first part of this volume, the author traces the wanderings of the nomadic Israelites, who, according to Dr. Hale, now comprise the Western peoples. Their acceptance of the gold standard of Nebuchadnezzar has benefited the world, but has led to no surcease from war and its devastations. Biblical references are cited in depicting the role of Assyro-Russia in chastisement of Western institutions.

Chemivision may be described as the integration of physics, chemistry, biology and the related sciences into our way of living.

In "Chemivision," the author advocates with renewed vigor and emphasis his philosophy of chemurgy. He is particularly bitter about the American petroleum industry in exploiting our unrenewable resources. The present-day gap between agriculture and industry is fast becoming so alarming that we appear on the brink of disaster. To the chemurgists, there is a simple solution to the problem. Man must cultivate the land in its entirety and harvest it fully.

Dr. Hale's literary tirades are stimulating and provocative. If, in this work, the author had confined himself to sociological migrations and problems stemming from the industrial revolution, he would have been on sounder ground.

We cannot agree with the author's statement: "With the advent of the Dark Age (1933) in America there was kindled within government circles a bitter animosity against agriculture." It is the reviewer's impression, that the

(*Continued on page 70*)

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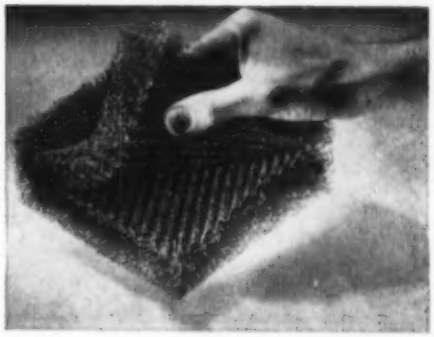

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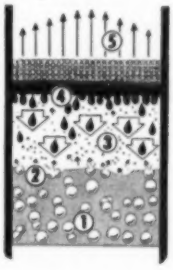

When a gas is generated in or passes through a liquid (1) it carries with it on leaving the surface (2) droplets of entrained liquid. These droplets are carried upward by the rising gas stream (3). As the gas continually changes direction in passing through the pad, the droplets are impinged on the extensive wire surface. Here the droplets coalesce, forming large drops of liquid which break away (4) from the pad and fall back through the gas stream. The gas (5) passes on, freed from liquid entrainment.

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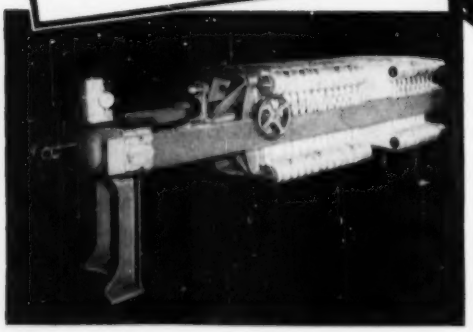

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MARGINAL NOTES

(Continued from page 69)

advent of parity, price supports, and the ever-normal-granary was friendly, if not a charitable gesture, on the part of government to farmers. Furthermore, chemurgy was given a generous start through the construction and operation of the U.S.D.A. Regional Research laboratories.

By way of refutation of Dr. Hale's thesis, let us assume that an additional billion bushels of corn is produced annually by stimulated production. This grain is worth about $1.50 a bushel. Let us further assume that the government would buy the grain and then sell it to distillers at 50 cents a bushel thus imposing a billion dollar loss to taxpayers. Alcohol obtained from grain at 50 cents a bushel cannot, however, compete favorably with synthetic methanol, ethanol or propanol which are the equal of grain alcohol as a motor fuel.

A few years ago when blackstrap molasses was selling at 20-22 cents a gallon, the U.S.D.A. offered surplus potatoes costing $2.40 a hundred-weight for 1 cent on farm site. A number of interested distillers and industrial firms gave this proposal serious consideration but finally concluded that the scheme was not practical because of transportation charges from farm to factory.

Chemivision is an interesting and provocative work. I urge you to read it.

Book Received

Organic Chemistry—An Advance Treatise. Vol. IV. Edited by Henry Gilman. John Wiley & Sons, Inc., New York (1953). xxxviii + pp. 581-1245, $8.75.

Radiation Suppressing Coatings for Metals at Elevated Temperatures. Special Report No. 1. A. H. Sully, E. A. Brandes, and R. B. Waterhouse. Fulmer Research Institute, Limited. Stoke Poges, Buckinghamshire, England, 24 pp. (1953), 15/-net.

Aluminum in Iron and Steel. Samuel L. Case and Kent R. Van Horn. (Alloys of Iron Research Monograph Series). John Wiley & Sons, Inc., New York (1953), 478 pp. $8.50.

Industrial Furnaces, Vol. 1. 4th ed. W. Trinks. John Wiley & Sons, Inc., New York (1951), 526 pp. $10.00.

Organic Reactions. Vol. VII. Roger Adams, Editor in Chief. John Wiley & Sons, Inc., New York (1953), 440 pp. $9.00.

Prevention and Resolution of Tar Emulsions in High-BTU Oil Gas Production. H. R. Linden and R. Parker. Institute of Gas Technology, Chicago, Ill. (1953), 16 pp. $2.50.

LOCAL SECTION NEWS

SOUTH TEXAS

Four technical sessions, including two symposia and one student session, are expected to attract more than 500 chemical engineers, executives and students to the Eighth Annual Technical Meeting of the South Texas Section to be held at the Galvez Hotel, Galveston, Tex., on Oct. 16.

The Welcoming Address at Session No. 1 will be given by W. B. Franklin, chairman of the South Texas Section, A.I.Ch.E., and J. J. McKetta, vice-chairman, South Texas Section, will welcome those present for the General Session.

The meeting will be concluded with a banquet at which the speaker will be C. G. Kirkbride, president, Houdry Process Corp., and Vice-President of A.I.Ch.E.

The program follows:

Session No. 1—Ball Room

SYMPOSIUM ON ECONOMICS AND COST ESTIMATING

Presiding: R. J. Phillips, The Gulf Publishing Co., Houston, Tex.

9:35 A.M.—CHEMICAL PLANT ECONOMICS by A. B. Horn, Ethyl Corp., Pasadena, Tex.

10:00 A.M.—ECONOMIC ANALYSIS IN PETROLEUM REFINING by J. P. Hamilton, Humble Oil & Refining Co., Baytown, Tex.

10:30 A.M.—COST ESTIMATING PETROLEUM PROCESSING UNITS by J. F. Silmore, Jr., Blaw-Knox Co., Tulsa, Okla.

11:00 A.M.—DEFINITIVE COST ESTIMATING by Harold Bottomley, Tulsa.

Session No. 2—Terrace Room

GENERAL SESSION

Presiding: N. P. Peet, Humble Oil & Refining Co., Baytown

9:30 A.M.—APPLICATION OF IBM MACHINES IN PETROLEUM REFINING by W. M. Harp, Humble Oil & Refining Co., Baytown.

10:00 A.M.—DEVELOPING ENGINEERS INTO EXECUTIVES by Robert F. Pearse, Worthington Associates, Inc., Chicago, Ill.

10:30 A.M.—WATER DEMINERALIZATION BY ION EXCHANGE MEMBRANES by W. E. Katy, Ionics, Inc., Cambridge, Mass.

11:00 A.M.—REAGENT GRADE AROMATICS BY THE TANK CAR by W. K. Jackson, Cosden Petroleum Corp., Big Springs, Tex.

Session No. 3—Ball Room

SYMPOSIUM OF INDUSTRIAL ORGANIC CHEMICALS

Presiding: P. C. White, Pan American Refining Co., Texas City, Tex.

2:00 P.M.—SYNTHETIC DETERGENTS by J. E. Kircher, Continental Oil Co., Houston.

2:30 P.M.—ECONOMICS OF DEVELOPING AN AGRICULTURAL CHEMICAL by R. H. Wellman, Carbide & Carbon Chemicals Co., Yonkers, N. Y.

3:00 P.M.—DEVELOPMENT OF EPON RESINS by T. A. Walb, Shell Chemical Corp., Union, N. J.

3.30 P.M.—SYNTHETIC FIBERS by C. H. Rutledge, Du Pont Co., Wilmington, Del.

Session No. 4—Terrace Room

STUDENT SESSION

Presiding: W. D. Harris, A. & M. College, College Station, Tex.

2:00 P.M.—JOB TRAINING PROGRAMS FOR TECHNICAL PERSONNEL by J. T. Moody, Humble Oil & Refining Co., Baytown.

2:30 P.M.—JOB TRAINING PROGRAMS FOR TECHNICAL PERSONNEL by T. J. Walker, Dow Chemical Co., Freeport.

3.00 P.M.—THE CHEMICAL ENGINEERING CAREER AFTER 5-10 YEARS by R. J. Phillips, Gulf Publishing Co., Houston.

3:30 P.M.—THE CHEMICAL ENGINEERING CAREER AFTER 15-20 YEARS by Mark Hopkins, Pan American Refining Co., Texas City.

SOUTHERN CALIFORNIA

The August meeting of the Southern California Section was something out of the ordinary. The subject was "Instrumentation," and a panel discussion with the audience participating covered such topics as: compressor control, fired heater control, and superfractionator control.

This was the first time the Southern California Section had tried a symposium-type meeting. Its success was noted in an attendance of more than 100 members and guests with the instrument and compressor companies well represented.

(Continued on next page)

IMPORTANT

Watch the October issue of C. E. P. for a complete story on the San Francisco meeting—a report on the technical papers presented, a running account of who met whom at the Fairmont or on the tours, and some interesting candid shots.

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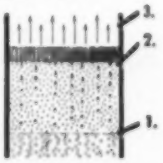

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The moderator was A. J. Fink, Taylor Instrument Co., and the speakers were C. G. Laspe, instrument engineer, Shell Oil Co. (compressor control), W. J. Baral, senior process engineer, Union Oil Co. (fired heater control), and E. H. Reynolds, light oil operating department, superintendent, Richfield Oil Corp. (superfractionator control).

The July meeting was the highlight of the year with more than 100 members journeying (some more than 70 miles) to the Fontana plant of the Kaiser Steel Corp. for dinner and a plant tour. The steel industry was described and displayed from the ore and coal mining operations through the coke ovens and blast furnaces to the open hearths and eventually to the rolling mills, and pipe and structural mills.

The September meeting speaker will be W. T. Nichols President of A.I.Ch.E. and director of the general engineering department, Monsanto Chemical Co.

OKLAHOMA

The Oklahoma Section will be host on Oct. 10 for the all-day meeting to be held in the College High School, Bartlesville, Okla. The morning session will consist of four papers on technical subjects. The luncheon will feature an address by W. T. Nichols, President of A.I.Ch.E., and the afternoon session will be taken up by a series of papers on Personal Improvement.

Each fall the Tulsa and Oklahoma Sections hold a state-wide meeting with the two sections alternating as hosts.

In 1952 Tulsa was host at the one-day meeting held Oct. 11 at the University of Tulsa.

SAVE THOSE BACK ISSUES

Every so often an unprecedented demand for a particular issue, or an unexpected influx of new subscribers and members puts the editor in the embarrassing position of running out of copies of Chemical Engineering Progress. This has happened several times in our short history and if members have copies of any of the following issues, we would be glad to purchase them. The issues which we need and for which we will pay 75 cents each are: April, 1947, December, 1952 and February, 1953.

All these issues were overprinted to a great extent, but because of features and other demands, single copy sales, etc., they were completely exhausted in a short time.

PEOPLE

Grayton F. Dressel, assistant since 1947 to the production manager of Inorganic Chemicals, Dow Chemical Co., has been named as his successor. Mr. Dressel started with Dow in 1924. He assisted in developing processes for extraction of bromine from sea water and from 1933 until 1936 was manager of an ethylene dibromide plant which he helped design and construct for Ethyl-Dow. Then followed a year as manager of Cliffs Dow Chemical Co., a subsidiary of which he is presently a director. He has served as vice-president of the now defunct Dow Magnesium Corp.

It has been announced that **John F. Ryan** and **H. Robert Sanders, Jr.** have joined the staff of Esso Laboratories, Standard Oil Development Co. Dr. Ryan completed his undergraduate work at the University of Illinois and his graduate work at Pennsylvania State College, receiving his master's degree and doctorate in chemical engineering. Mr. Sanders received his B.S. and M.S. degrees in chemical engineering from Virginia Polytechnic Institute.

Robert W. Michaels is a new member of the research department of Standard Oil Co. (Ind.) at Whiting, Ind. Dr. Michaels obtained his Ph.D. in chemical engineering at the University of Wisconsin.

Ralph M. Hunter has recently been advanced to the position of staff coordinator of all electrochemical activities for the Dow Chemical Co., Midland, Mich. In his new capacity Dr. Hunter will coordinate electrochemical operations on a company-wide basis and facilitate the exchange of research and development information, retaining active charge of the Midland Electrochemical Laboratory. For several years Dr. Hunter was president and a director of the Midland Ammonia Co. Currently he is a director of Dow Chemical of Canada, Ltd.

Lawrence Lynn was named head of the plastics division, process engineering section, Celanese Corporation of America. A graduate of Texas A. & M., and Columbia University, he joined the company in 1949.

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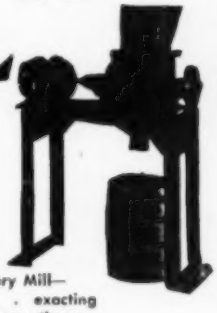

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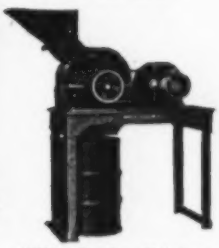

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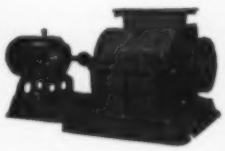

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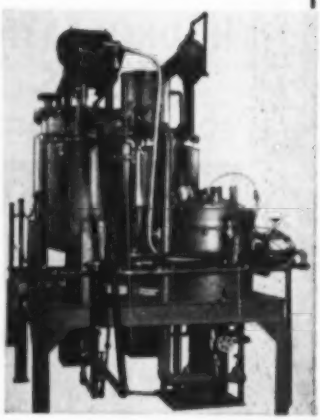

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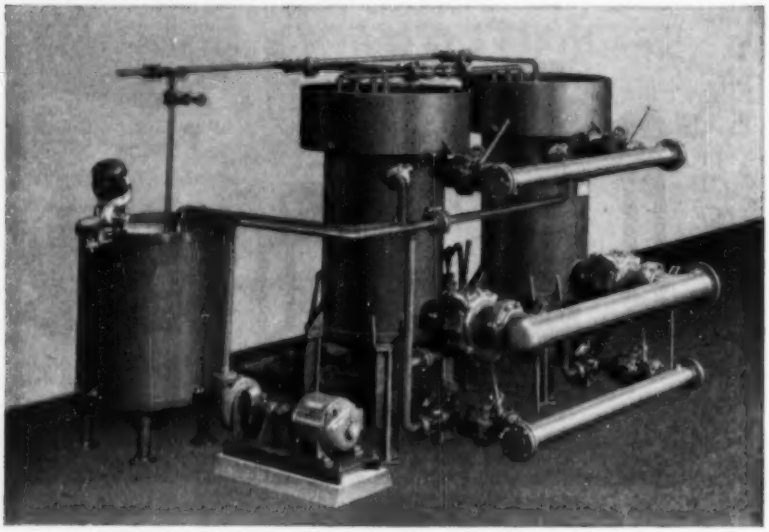

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Frederick G. Sawyer, previously assistant to the director of research at Stanford Research Institute, has recently joined The Ralph M. Parsons Co., Los Angeles, Calif. He will be engaged in special projects in the fields of chemical and petroleum engineering, and technical public relations. For two years Dr. Sawyer was with the central research laboratory of the American Cyanamid Co., Stamford, Conn. His work there concerned colloidal studies on suspensions of resins used in paper manufacture. Subsequently he was transferred to the New York office of the company where he was with the technical service department. Late in 1946 Dr. Sawyer went to Washington, D. C., and spent seven months with the research and development division, general staff, War Department.

G. P. MEADE HONORED AS SUGAR PIONEER

George P. Meade, manager of the Gramercy (La.) refinery of Colonial Sugar Co., was designated "Man of the Year" at a dinner given by the Carbohydrate Division of the American Chemical Society on Sept. 9.

Mr. Meade, who is co-author of the "Cane Sugar Handbook" and an authority on sugar technology, has been in the sugar industry since he received his degree in chemical engineering from New York University in 1905. He was the only man in his class to receive the degree. In 1911 he became a member of A.I.Ch.E., after working for some months under Ferdinand G. Wiechmann, one of the charter members of the Institute and a leader in the sugar field.

In 1917 Mr. Meade designed a sugar plant, at Cardenas, Cuba, so far in advance of contemporary refineries that it is still in production. It was the first refinery in the Western Hemisphere to discard bag filters in favor of Sweetland filters and pressure filtration with an inert filter aid.

William H. Darnell, who has just received a Ph.D. in chemical engineering from the University of Wisconsin, will join the polychemicals department of Du Pont Co., Wilmington, Del.

Harold W. Wheeler, formerly operations manager at the Ethyl Corp., Baton Rouge, La., plant, has been made assistant director of industrial relations for the manufacturing department's Baton Rouge and Houston plants. He is a graduate of Northeastern University. Mr. Wheeler helped organize and was the first chairman of the Baton Rouge Local Section.

William E. Yates has been appointed resident manager of the Lawrence, Kan., plant by Westvaco Chemical Division, Food Machinery and Chemical Corp. Previously, assistant plant manager, Mr. Yates has been with Westvaco since 1941, serving in various research department capacities at the South Charleston, W. Va., plant before the appointment as staff assistant at Lawrence in 1950. He holds an M.S.Ch.E. from Iowa State College, and an A.B. and B.S. from Northwest Missouri State Teachers College.

Gordon D. Kerns, formerly associated with the Sun Oil Co. at Marcus Hook, Pa., is a recent addition at the Whiting Research Laboratories of the Standard Oil Company (Ind.).

Donald W. Collier, director of research, Thomas A. Edison, Inc., has been elected a director of the Atomic Instrument Co., Inc., Boston. Prior to his association with Edison he was in the research laboratories, Sharples Corp., Bridgeport, Pa., as chemical engineer in charge of process development. Dr. Collier received his Ph.D. (1944) from Princeton University. As head of Edison Laboratory, Dr. Collier, occupies the position created and held by the late Thomas A. Edison.

Gustav Egloff, director of research, Universal Oil Products Co., has been elected an honorary fellow of the Royal Society of Edinburgh. This Society was instituted by royal charter in 1783 for the promotion of science and literature.

Robert E. Zinn has been appointed professor of chemical engineering at Northwestern University Technological Institute. For two years prior to his appointment he had been a professional lecturer in chemical engineering at the Institute. On joining the faculty in 1951 he terminated twenty-four years' employment with the Victor Chemical Works, Chicago Heights, where he began as a junior chemical engineer in 1927 and rose to the position of chief engineer. At present he is associated with the Vern E. Alden Co., as a consulting chemical engineer.

Scientific Design Co., Inc., has announced the appointment of **Philip Edward Newman** as European representative. Prior to this appointment, Dr. Newman was chief chemical engineer and project manager for the Pechiney Company of France. Before entering the army, where he served as a captain in the Corps of Engineers and operations officer in the Military Government Control of the German chemical industry, Dr. Newman was engaged in research at the Mellon Institute as an assistant fellow. He also served with the Hercules Powder Co. as chemical engineer in production and plant operation problems.

Burton B. Crocker has been named an assistant chief engineer of the phosphate division, engineering department, Monsanto Chemical Co., Anniston, Ala. He had been serving in an advisory capacity to the phosphate research group at Dayton, Ohio. Prior to his work at Dayton, he spent four months in Paris as adviser on the design of a phosphorus plant in France for Societe de Produtis Chimiques Coignet, a Monsanto affiliated company. He joined Monsanto in 1945 after four years in the Army Ordnance Corps in World War II.

James O. Maloney, chairman of the department of chemical engineering, and director of the University of Kansas Research Foundation, was a guest on a trip to Venezuela, of the Shell Oil Company of Venezuela. He visited its operations at Caracas, Cardon, and Maracaibo.

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DAVID E. PIERCE NOW A CONSULTANT

David E. Pierce, associated with General Aniline for eleven years, first as chief engineer of the General Aniline Works Division and later of the General Aniline & Film Corp., is now engaged in consulting practice in New York City. He will be chiefly concerned with maintenance budgeting and control, which may involve a study of the organization and operation of maintenance departments so that the best use may be made of the Variable Budget System.

A graduate of the Massachusetts Institute of Technology, Mr. Pierce has been associated with the Du Pont Co., Atlantic Refining, and Rohm & Haas.

Clyde McKinley has been appointed director of research for Air Products, Inc., of Allentown, Pa. effective Sept. 1. During the past ten years Dr. McKinley has been associated with the research staff of the General Aniline and Film Corp.

John E. McKeen, president, Chas. Pfizer & Co., Inc., Brooklyn, N. Y., was awarded the Order of Vasco Nunez de Balboa, with rank of Knight Commander. This decoration, Panama's highest civilian honor, was given to Mr. McKeen by order of the President of the Central American republic. Mr. McKeen is also a director of the World Medical Association, the Health Information Foundation, and the National Vitamin Foundation.

Raymond H. Ewell, manager of the chemical economics service of Stanford Research Institute, has been given an extended leave of absence to become assistant director for Program Analysis in the National Science Foundation, Washington, D. C. In his post with the Foundation Dr. Ewell will have charge of a program of studies on research relating to the development of a national science policy. The program will embrace the mathematical, physical and biological sciences, and particular emphasis will be placed on an appraisal of the economic and social values of both basic and applied research. Dr. Ewell, a Ph.D. from Princeton in 1937, joined Stanford Research after three years with Shell Chemical Corp. as chemical economist. He is co-inventor of the Lecky-Ewell packing for fractionating columns.

R. C. GUNNESS ON STANDARD OIL BOARD

Robert C. Gunness, assistant general manager of manufacturing, Standard Oil Company (Indiana) was recently elected to the Board of Directors to fill the place on the board vacated by H. F. Glair, retired. Dr. Gunness, who has spent his entire business career with Standard Oil, was on leave for several months in 1951 to serve as vice-chairman of the Research and Development Board of the Department of Defense in Washington, D. C.

C. E. Rowe has been appointed assistant to the vice-president and director of operations of Mathieson Hydrocarbon Chemicals Division, Mathieson Chemical Corp., with headquarters in the executive office at Baltimore, Md. He was formerly assistant operations manager at Mathieson's Doe Run, Ky., plant, where he was responsible for maintenance and construction.

John D. Jay has been transferred from the research staff of the polychemicals department at the Experimental Station of Du Pont at Wilmington, Del. to the manufacturing division at the Sabine River Works, Orange, Tex. At Orange he will be a production supervisor in the Alathon polyethylene resin division. Mr. Jay joined the company as a chemical engineer in 1942 and recently has been coordinating engineering and mechanical services for the research division and forecasting and planning engineering facilities. He received his B.S. from Iowa State College.

Russell G. Dressler has been appointed technical assistant to the president of Atlas Powder Co., with headquarters in the general office at Wilmington. In 1939, when he received his Ph.D. in organic chemistry from the University of Southern California, he joined Colgate-Palmolive-Peet Co. as research chemical engineer. Subsequently he served the Army Chemical Corps as a senior chemical engineer and the California Research Corp. in charge of all pilot plant operations. Since 1946 he has been associated with the U. S. Bureau of Mines as chief of its gas synthesis demonstration plant at Louisiana, Mo.

Melvin Rozene, assistant to the chief engineer since 1952, has been appointed senior assistant director of engineering, River Road plant, Bakelite Co., a division of Union Carbide and Carbon Corp. He joined Bakelite as a technical assistant in the Works Laboratory in 1941, and was assigned to the engineering department in 1946.

C. P. Orr

F. P. La Belle

LA BELLE AND ORR ADVANCED BY MONSANTO

Appointment of Francis P. La Belle as assistant chief engineer and Clyde P. Orr as chief chemical engineer of the phosphate division of Monsanto Chemical Co. was recently announced. Mr. La Belle has been chief chemical engineer of the division in Anniston and Mr. Orr has been assistant manager of the process section of the general engineering department in St. Louis.

Joining Monsanto in 1941 at the Anniston plant after receiving a B.S. degree in chemical engineering from Michigan State College, he transferred to the plant engineering department of the Trenton (Mich.) plant a year later. Returning to Anniston he subsequently became assistant chief chemical engineer and then chief chemical engineer.

Following his graduation from the University of Tennessee in 1942 with a B.S. in chemical engineering, Mr. Orr joined the Merrimac division at the Everett (Mass.) plant of Monsanto. He transferred to the general development department in St. Louis and subsequently was named a process engineer in the general engineering department.

The promotion of **James E. Deas, Jr.,** to the position of assistant chief chemist in charge of the Technical Service Group at the Covington plant of Industrial Rayon Corp. has been announced. Dean was previously attached to the production superintendent's staff. A chemical engineering graduate of North Carolina State College, Deas joined Industrial Rayon in 1949 as a supervisory trainee and was elevated to the production superintendent's staff in 1950. Prior to his association with Industrial Rayon, he was with the department of engineering research, North Carolina State College.

Jackson D. Leonard, a consulting chemical engineer with office in Metuchen, N. J., has announced that he will leave soon on an extended trip to Japan, Burma, the Philippines, and India to render assistance to the chemical industry in these areas.

(More about People on page 80)

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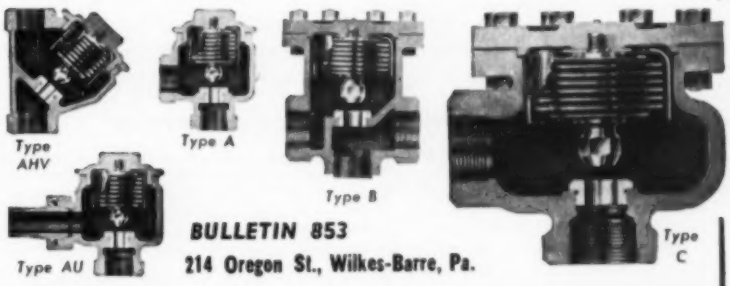

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To work with head of chemical engineering division. Guide experimental projects, handle consulting inquiries, proposals, liaison, and technical reports. An interesting opportunity for a resourceful and personable chemical engineer who has supplemented an excellent formal education with six to eight years of solid professional experience, and who seeks responsibility above normal for his age.

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We are an old well-established Midwest chemical manufacturer who has a substantial opening in our safety program. To fill this we want a man with a positive and persuasive personality who is capable of inaugurating, "selling" and carrying out a comprehensive safety program. He must have a degree in chemical engineering or chemistry with at least five years' responsible industrial safety experience in a chemical manufacturing plant. Preferably he should be a member of the American Society of Safety Engineers.

The man selected will be given responsibility for the safety program of a large division of the company, will be expected to direct the work of others in the divisional Safety department, and will be paid a salary commensurate with the responsibilities involved.

Please submit complete résumé of personal data, education, previous experience, salary received and expected, and references in that order. All replies treated in confidence. Box 6-9.

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For project evaluation, process and equipment design and engineering development in vinyl resins. Medium-sized growing company, leader in field. Eastern location. Experience necessary, salary commensurate. Submit résumé of experience and background. Box 3-9.

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CHEMICAL ENGINEER — SALES CORRESPONDENT — Progressive Midwest manufacturer has opening for ambitious young engineer, preferably chemical, to handle correspondence and gradually assume responsibilities of office management. Will be given opportunity to learn filtration from both technical and practical viewpoints and may develop without limitation into field sales work. Salary open. Submit résumé and salary desired. Box 24-9.

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WANTED—Fairly recent graduate with M.S. or Ph.D. degree for work with colloids and other organics. Location Middle West. Reply giving age, experience and salary desired. Box 25-9.

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Reply giving age, experience, grades in technical subjects, several technical references, general salary expectation.

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CHEMICAL ENGINEER—Registered professional engineer. Age 43. Twenty-four years' experience in production and plant design. At present am a senior engineer in charge of seven project engineers for a pharmaceutical and biological firm. A position of chief or assistant chief engineer or equivalent is desired. Box 7-9.

CHEMICAL ENGINEER — M.S.Ch.E. Three years' experience in pilot plant supervision and development. Desire production or development position in southern California. Age 26, married, veteran, Q-cleared. Box 8-9.

CHEMICAL ENGINEER—B.S. Graduate studies. Publications. Ten years' diversified experience in petroleum, food, minerals industries. Includes complete plant and pilot plant design, equipment selection, economic studies, initial start-ups, plant operations, supervisory experience. Age 32. Minimum salary $8,500. Box 9-9.

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CHEMICAL PROCESS ENGINEER—B.S.Ch.E. 1937. Florida. Age 38, family. Twelve years' experience in supervision of diversified chemical operation and construction, including labor relations. Desire supervision-management of operations. Prefer South. Box 19-9.

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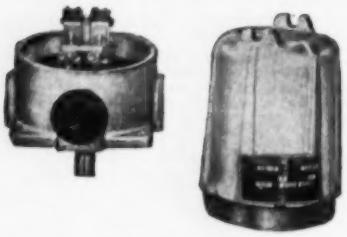

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PEOPLE

(*Continued on page 77*)

R. A. WILSON, VICE-PRES. OF SHEA CHEMICAL

The appointment of Robert A. Wilson, manager of the Process Engineering Division of the Air Reduction Co., since 1948, as vice-president for engineering and production, Shea Chemical Corp., was recently announced. He will be located at the firm's executive office in Baltimore, Md. Mr. Wilson, a graduate of the Georgia Institute of Technology, was employed by the Tennessee Valley Authority as a chemical engineer, 1937-1947; and by the Monsanto Chemical Co., 1946-1948.

Eli Zinn has joined the staff of research and development department, Diamond Alkali Co., Painesville, Ohio, as a project engineer on pilot-plant operations. He was previously engaged in development work at Commercial Solvents Corp., Terre Haute, Ind. Mr. Zinn received his bachelor's degree in chemical engineering from Cooper Union in 1940 and took postgraduate work in chemical engineering at Brooklyn Polytechnic Institute.

Arthur E. Humphrey recently completed his graduate studies at Columbia University and accepted a position as assistant professor of chemical engineering at the University of Pennsylvania. Dr. Humphrey's undergraduate and earlier graduate training was obtained at the University of Idaho.

It has been announced that **Kenneth L. Meyer** has been promoted from the position of assistant plant engineer to plant engineer of Hiram Walker & Sons, Inc., Peoria, Ill. He will be responsible for the handling of the various phases of engineering in the Peoria plants with the exception of maintenance operations. Mr. Meyer is a graduate in chemical engineering from the University of Iowa and has been with the Hiram Walker company since 1936.

James M. Duncan, formerly assistant professor of chemical engineering at the University of Florida, and **[illegible] ion P. Lelong**, formerly Fellow, Marble Fellowship, Mellon Institute of Industrial Research, have joined the staff of Patchen and Zimmerman, Engineers, Augusta, Ga. The new incumbents have been initially assigned to assist the research department of the Monsanto Chemical Co., Anniston, Ala.

Virgil D. Drummond has joined the Lummus Co. in the capacity of assistant to Dr. E. R. Smoley, vice-president. He will be engaged in sales engineering work.

INDEX OF

	Page
A	
Abbé, Inc., Paul O.	48
Adams Co., Inc., R. P.	74
Aerco Industries	74
Aldrich Pump Co.	55
American Pulverizer Co.	73
American Society for Metals	77
Artisan Metal Products, Inc.	73
B	
Babcock & Wilcox Co., Tubular Products Div.	13
Badger Manufacturing Co.	8
Baker Perkins, Inc.	67
Bartlett & Snow Co., The C. O.	53
Bowen Engineering, Inc.	41
Burling Instrument Co.	80
C	
Carbide & Carbon Chemicals Co., A Division of Union Carbide and Carbon Corp.,	*Inside Front Cover*
Catalytic Construction Co.	18
Chemical Corporation	60
Chemical Industries Exposition	66
Corning Glass Works	42, 43
Crane Company	14
Croll-Reynolds Co., Inc.	81
D	
Dorr Company, The	50
Dow Chemical Co.	23
Dow Corning Corporation	58
Doyle & Roth Mfg. Co., Inc.	12
Duraloy Company	51
E	
Eimco Corporation	45
Engineering Corp. of America	77
F	
Filtration Engineers, Inc.	76
Fischer & Porter Co.	49
Fluor Corp., Ltd.	32
Foxboro Co.	29
G	
General American Transportation Corp.	11, 454, 57
General Industrial Development Corp.	75
Girdler Company, The	5
Great Lakes Carbon Corp., Electrode Division	7
Gump Company, B. F.	3
H	
Hanovia Chemical & Mfg. Co.	62
Hardinge Co., Inc.	54
Haveg Corporation	56
Hilliard Corporation	22
Hills-McCanna Co.	59
I	
International Nickel Co., Inc.	61
J	
Johns-Manville	65

ADVERTISERS

	Page
K	
Kinney Mfg. Co.	9
Knight, Maurice A.	52
L	
Lawrence Pumps, Inc.	10
Little, Inc., Arthur D.	31
Louisville Drying Machinery Unit, General American Transportation Corp.	11
M	
Metal Textile Corp.	69
Milton Roy Company	*Inside Back Cover*
Minneapolis-Honeywell Regulator Co.	24, 25
Mixing Equipment Co., Inc.	*Back Cover*
N	
National Carbon Co., A Division of Union Carbide and Carbon Corp.	27
Niagara Filter Div., American Machine and Metals, Inc.	21
Nicholson & Co., W. H.	77
P	
Pan American Chemicals Div., Pan American Refining Corp.	70
Pfaudler Company, The	16
R	
Republic Flow Meters Co.	30
Rohm & Haas Co.	63
S	
Sargent's Sons Corp., C. G.	47
Sharples Corp., The	64
Shriver & Co., Inc., T.	70
Sparkler Mfg. Co.	15
Spraying Systems Co.	46
Struthers Wells Corp.	6
T	
Turbo-Mixer Div.	454
U	
Uehling Instrument Co.	74
Union Carbide & Carbon Corp., Carbide and Carbon Chemicals Co., *Inside Front Cover* National Carbon Co.	27
United States Gasket Co.	4
U. S. Stoneware Co.	17
V	
Vanton Pump Corp.	46
Y	
York Co., Inc., Otto H.	71

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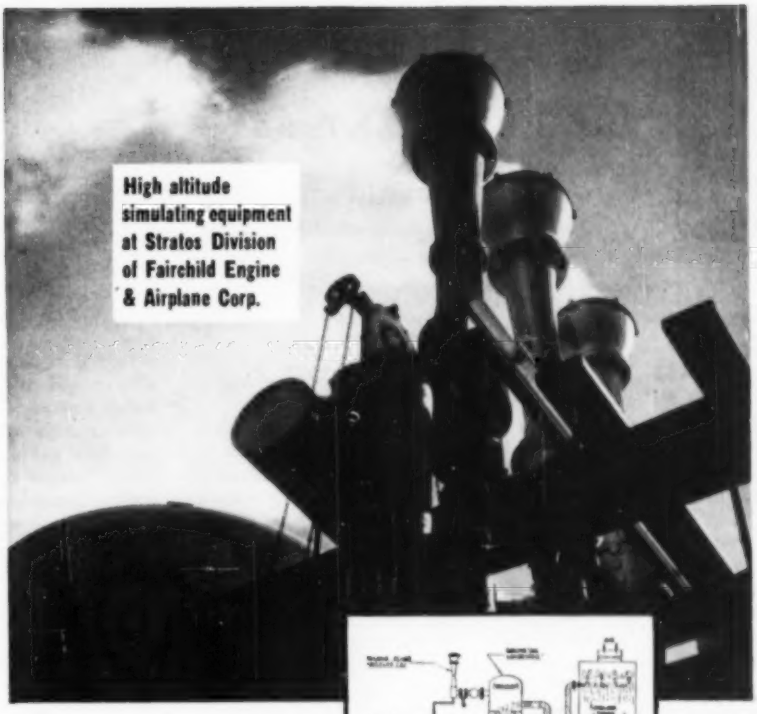

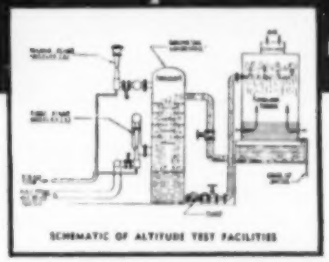

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THE PRESIDENT SAYS

A controversial question among members of the Institute is the one about membership grades and qualifications. Feelings seem to run high on matters of this kind. Although our members may not come to blows over such questions, I have witnessed some pretty rugged arguments. To be truthful I have been a party to many such battles and, in retrospect, am afraid that a lot more heat than light was generated. What causes the intensity of feeling is the fear, that changes in constitutional requirements for membership will, in fact, be relaxations of standards and result in degradation of our society and our profession.

I suppose a certain mellowness comes with advancing years. I now seem able to think about these questions of membership grades quite dispassionately, in a manner that would have been inconceivable some years ago. The Institute is older, too. Our circumstances have changed. At the risk of inciting to riot some of those who are most frequently vociferous on these subjects, I propose to discuss membership grades and privileges as I now see them.

In the first place I firmly believe that we have done a good job of maintaining a high standard of membership in the organization. So good a job could not have been done and would not have been done had not a few devoted souls steadfastly held the line when our principles were under attack. I would not suggest now that we lower our standards but determine whether we can improve our membership arrangements. In an earlier column I mentioned the fact that Arthur Doolittle was making a study of membership grades, employing several members of the Charleston Section to help him. Council now has his report as well as the first figures from our national survey. In due course these results will be available to all members. What I offer now is strictly my own personal slant on membership questions.

One subject that has bothered me a great deal, over the years, relates to teachers of chemical engineering. It used to be true that such teachers had great difficulty in fulfilling requirements for Active membership because our Constitution places such great emphasis on *practice*. Teachers could qualify by proving that they had practiced chemical engineering and had had responsible charge of important chemical engineering work prior to engaging in teaching, or by research or consulting activities while engaged in teaching. Arguments over teacher cases inside and outside the Committee on Admissions used to focus on the nature of the teacher's experience. Was there enough *practice* of chemical engineering? Of late years the tendency has been increasingly to consider bona fide teaching as equivalent to practice and with this I fully agree. To further the objects of our Institute—"the advancement of chemical engineering in theory and practice and the maintenance of a high professional standard," the teaching of chemical engineering is, I believe, at least as important as *practice*, and experience in teaching should be at least as good as practice for discharging full responsibilities of membership. I would not advocate just sweeping into our membership all those connected in any way with chemical engineering education. I would simply apply the same sort of criteria for experience and responsible charge as we apply to the practice of chemical engineering.

A question of considerable importance is whether Junior members should vote. I can take either side of the question and argue with some conviction. All shades of opinion are held among people for whose opinions I have respect. Some say no, on the basis that older heads are wiser and that young men can later on achieve voting status. The franchise is not denied them forever. What concerns some is that a young man might become a voting member long before it is clear that he will remain in the profession or that he will, in fact, become a chemical engineer in actuality. Some years ago we removed the age limit on Active members so as to make merit rather than age the basis. Those who fear the voting franchise for Junior members are, of course, afraid that the young and impulsive will gain control of Institute affairs and make unwise and serious moves.

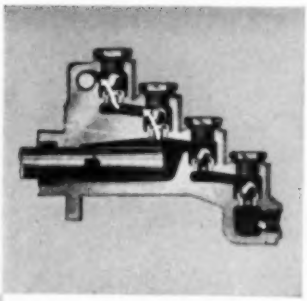
My own view is that we should maintain a top membership grade, corresponding to the present Active grade, based upon proven experience and responsibile charge in the practice *and teaching* of chemical engineering. We should have a subsidiary grade of membership encompassing substantially those now comprising our Junior and Associate membership. In this subsidiary grade those could remain who have a direct interest in our field but who can not qualify for the top grade. I believe all members should be able to vote in elections but I would restrict voting on constitutional amendments to the top membership grade.

It will thus be seen that I do not lack confidence in the good judgment of our members just because they are young. I have seen chemical engineers just a few years out of school handle big, difficult, and important jobs in wartime when necessity compelled us to put responsibility on them. I simply do not believe that our younger members would vote into office a group of unworthy, incompetent people who would "wreck the Institute." They would be no more likely to do this than would the present voting membership. If we who are older and have had more experience can not earn the confidence of our younger people and make our advice and guidance acceptable, then perhaps there is no reason for us to guide the destiny of the Institute.

Officers and directors should be chosen from among the top-grade members. There is a wide age range in this grade and Council need not consist entirely of the aged and decrepit. With the suggested arrangement all those who pay dues and participate actively in Institute affairs would have the voting franchise, with only one exception. Restricting voting on constitutional amendments to those who have demonstrated enough ability and interest in chemical engineering to qualify for top-grade membership would be insurance against even the unlikely event of unwise policy changes voted in by members not yet permanently established in the profession.

Such a membership as I describe might be covered by two grade names, such as *Member* and *Associate*. This, then, would be in line with what is going on among major engineering societies to try to create practically parallel membership grades and requirements for all. Possibly the term *Affiliate* might be used for persons whose interest is not so direct or intensive as in the other cases. It is a matter that I should like to see arranged by means of constitutional amendment at an early date.

W. T. Nichols



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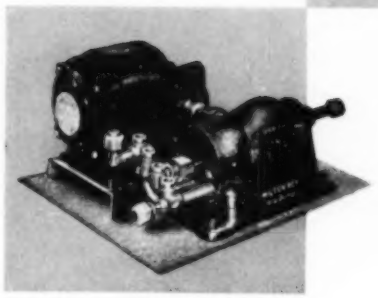

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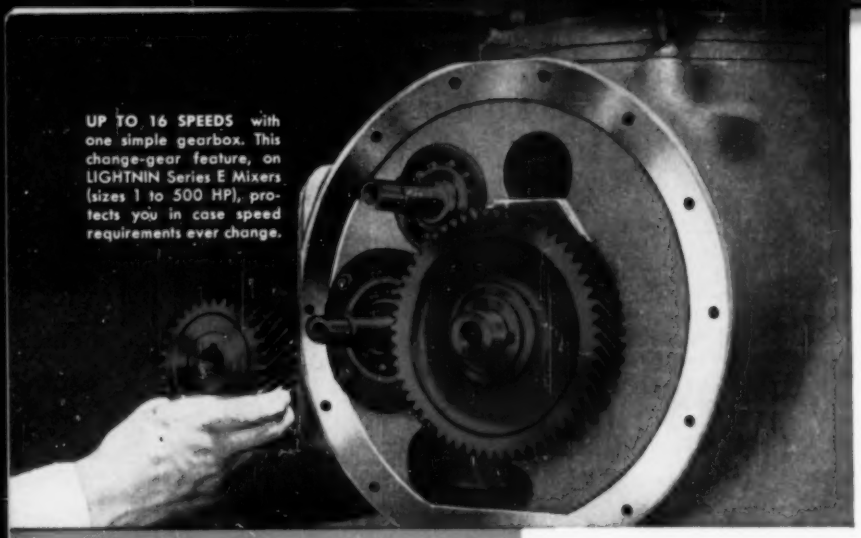

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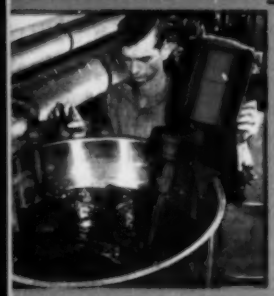

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